Annual Progress Report
Decision Aids for Integrated Soil Nutrient Management
February 11, 2000 - February 10, 2001

Executive Summary

Several project activities were either curtailed or stopped during Year 4 to ensure that development of the final version of the NuMaSS software was not compromised by the 13% budget cut. Interim software releases were scaled back and travel to interact with and obtain feedback from extensive network collaborators on software performance was reduced to one trip each to Ecuador and Thailand/Laos.

Software release and evaluation - without the workshop for evaluation of NuMaSS in Year 4, we felt it was important to ensure that any possible user feedback was was incorporated to a interim release of NuMaSS version 1.5 which contained the following improvements over version 1.0: the inputs for each run can be saved, retrieved and re-edited; a check against typos when entering data is provided (range check); and different keyboard configurations for decimal nomenclature can be accommodated. Approximately 140 NuMaSS 1.5 CDs were distributed to collaborators in May and an additional 35 copies were sent to other researchers and managers in both the public and private sectors. Substantial progress was made on NuMaSS 2.0, scheduled for release in Year 5. The diagnosis portion of the interface has been reorganized and simplified based on user feedback. The interface is now much easier to navigate and fewer inputs are required. As navigation has become easier for the user, programming has become more difficult and time consuming. The interface was changed to accommodate an additional crop - peach palm. Over 60 images of plant nutrient deficiencies have been added to the software to facilitate user selection of deficiency symptoms in the diagnosis section. Based on success in addressing nutrient management concerns on an agro-ecological basis, regions of all tropical countries were delineated into three major zones: semi-arid, humid tropical and wet/dry. Agro-ecological zones can be selected in the Geography section or by clicking on a digitized world map. Probabilities for diagnosing N deficiencies and acidity constraints were developed from user survey information to provide a uniform and integrated diagnosis across all nutrients addressed. The project's web site (http://intdss.soil.ncsu.edu) continues to serve as the primary conduit for communications on project activities among U.S. and overseas participants, as well as the general public.

Intensive testing sites -

Costa Rica - measurements were completed for 52-week monitoring of the dry matter distribution and nutrient accumulation among harvested and recycled components of mature peach palm stands in Costa Rica. The combined data for harvested and standing biomass and nutrients reveals the following aspects concerning annual budgets for mature peach palm stands: 1) a total production of 19.0 t ha^{-1} of aboveground dry biomass, of which 69% is cut each year and only 8% is removed for commercial processing of heart-of-palm; 2) the order of ranking for nutrient accumulation is the same in both harvested and standing biomass - K . N>Ca>P>Mg; and 3) of the total nutrient stock in the biomass, quantities exported from the field range from 9% for N and Ca to 11% for P and K. Annual nutrient release in recycled foliage mulch ranges from 67% for Ca to 96% for K. Total aboveground standing biomass for stands up to 20 years old were fit to logistic functions and revealed maximum biomass stabilizing at 5.5 t ha^{-1} at 10 years in stands with < 4200 plants/ha, and 3-4 years in stand with > 4200 plants/ha. Excavations

of plant bases and coarse roots revealed relatively large stores of biomass and nutrients are sequestered belowground in peach palm ecosystems. Cummulative heart-of-palm yields for 29 weeks doubled between fertilizer N rates of 0 and 200 kg ha^{-1} $year^{-1}$, with no additional response between 200 and 400 kg N ha^{-1} $year^{-1}$. Heart-of-palm yields over 12 months did not increase with P fertilization, although soil levels were quite low. Responses to P additions in Brazil were observed in experiments where neither foliar P (young and old leaves) nor soil P at 0-5 and 5-20 cm depths) predicted that a yield response would occur.

Mali - estimates of P buffer coefficients from laboratory incubations compared remarkably well with NuMaSS predicted values for a series of soils in Mali. This suggests that the laboratory incubation is a useful approach for predictions of P requirements in West Africa soils where prior soil test data may not be available. Contrary to local researcher experience and existing prices, 16% of the farmers in the Cinzana region reported use of inorganic fertilizers. Further investigation revealed that fertilizers are applied to selected areas of pronounced nutrient deficiency, rather than uniform applications to entire millet fields. Farmers' reasons for complementing manure applications with fertilizers were to (1) compensate for farmyard manure shortages, (2) poor nutrient quality of the manures, or (3) improve yield of late plantings. Inoculation of cowpea with a mixture of Bradyrhizobium strains from Zimbabwe (N0P2L2)did not increase seed or total biomass yields compared to the control (N0P2L0). Apparently, the indigenous strains had sufficient nitrogen fixation to support N requirements for yield levels under these soil and environmental conditions. An indirect estimate of the amount of N fixed by the cowpea crop is that 28 kg N/ha or 43% of the 65 kg/ha of accumulated N was derived from symbiotic nitrogen fixation.

Philippines - on-farm tests to compare NuMaSS and regional nutrient recommendations with farmer practices and no fertilizer inputs continued with rice and corn in the acid upland soils of Ilagan, Luzon and Arakan Valley, Mindinao. There was a high degree of accuracy in diagnosing constraints of N, P and acidity by NuMaSS. However, the yields achieved for both upland rice and corn were substantially lower than the target yields for which NuMaSS diagnoses and recommendations were made. In general, NuMaSS recommendations resulted in similar yields as the regional recommendation both at the more acid upland site in Ilagan, Isabella and at the less acid site in Arakan Valley for both upland rice and corn crops. Thus, NuMaSS performed as well as the regional recommendation. Peanut, soybean and mungbean BNF were determined by using the total N uptake of a non-nodulating soybean isoline that was included as one of the treatments in experiments at Ilagan. The major effect on BNF was from P application; soybean BNF and total N increased substantially while total N and BNF of peanut and mungbean was influenced less so. The total N uptake was strongly related to P uptake in all legumes. For every unit uptake of P, there was a corresponding uptake of approximately 9 kg N ha^{-1}. It appears that P fertilzation is the key to realizing increased inputs of BNF in acid uplands such as in Ilagan, Isabella, Philippines. Field and laboratory data during the last two crop seasons at Ilagan reveals that rice responded to P in one of two crops, but there was no response to lime or N. Corn responded to lime and P in two crops, but only responded to N in one crop. Peanut, soybean and mungbean responded to P, but response to lime only occurred when green manure was also applied. Preliminary estimates of critical Mehlich 1 P levels in mg kg^{-1} of soil are 6 for rice, 9-18 for corn, 6 for peanut and 5 for soybean.

Enhancing the acidity, N and P knowledge base -

Acidity - Nitrogen fertilization during two corn crops led to rapid acidification of kaolinitic Alfisols at Ibadan, Nigeria. Ammonium sulfate decreased soil pH (water) from 6.2 to 4.5. Incorporation of *Alchornea cordofolia* residue retarded the rate of acidification and leaching of Ca, Mg and NO_3-N during cropping. Movement of NO_3-N in the soil profile corresponded to that of Ca and Mg. Two-year comparisons of Ca movement were completed in Cinzana, Mali on clayey (40%) and sandy soils treated with four rates of lime and corresponding amounts of Ca supplied as Telemsi PR and gypsum. After two millet crop cycles, there was no evidence of Ca movement below 7.5 cm in either soil. Collaborators from Kwazulu-Natal, South Africa provided data for lime trials with *Phaseolus* beans that strengthens the NuMaSS database on this commodity. Critical Al saturation for dry beans across trials on four separate soils was 15%.

Nitrogen - Literature review, data assembly and interpretation for determination of N coefficients was completed for corn, millet and sorghum. Aboveground N accumulation for corn in Africa and Latin America ranged from 0.017 to 0.027 kg N/kg of grain yield. Fertilizer N requirements to achieve optimum yields ranged from 36 to 107 kg ha^{-1}, but were not related to maximum yields which ranged from 3.7 to 7.0 t ha^{-1}. Fertilizer N efficiency values for corn were similar among regions and ranged from 41 to 47%. Fertilizer N efficiency values for most millet trials were similar to corn, but N accumulation and grain:stover ratios varied considerably among both hybrids and improved varieties. A preliminary model to predict N derived from BNF by legumes was developed based on data collected during early soybean growth.

Phosphorus - laboratory incubations to estimate P buffer coefficients were completed for 62 soils (primarily Andisols and Ultisols from Central America). In Andisols, clay content was not related to P buffer coefficients as previously documented for Ultisols and Oxisols. The best predictors for P buffer coefficients in Andisols were either oxalate- or KOH-extractable Al. Critical soil P levels for upland rice and soybean in an acid, soil at Sinoloan, Philippines varied among cropping seasons and increased with the plateau yield level. The soils slow reaction coefficient for applied P was 24% less than the value predicted by NuMaSS. A modified nonlinear regression procedure was developed to extend the applicability of the linear response plateau. Collaborators in Ecuador provided data for three consecutive years of potato trials on Andisols at two separate sites. The field data enable estimation of slow reactions of fertilizer P with the soil over time and critical soil P levels. The Modified Olsen critical soil P level was estimated as 38 mg dm^{-3} across both sites, which was similar to the value of 46 mg kg^{-1} for 19 sites in Western Australia with clay contents ranging from 2-9%. Collaborators in Central Thailand provided opportunities to compare estimates of soil P diagnosis and fertilizer requirements by NuMaSS and local systems for maize. Diagnosis of field kit tests essentially matched those of laboratory soil analyses. Post-harvest soil P values were close to the values predicted by NuMaSS. Although amounts of fertilizer P determined by farmers' methods and NuMaSS were very similar, the latter did a better job of predicting sites were there would be a response.

Introduction

The goal of this project is to integrate and disseminate decision aid tools that will reduce soil acidity and nutrient limitations to food production and quality. The tools will facilitate the diagnosis of soil nutrient constraints and help the user to select appropriate management practices for location-specific conditions.

The 5-year plan for project tasks are organized into two major categories: *developmental research* and *outreach activities*. Developmental research includes tasks to do the following:

- merge the single-constraint decision support systems (DSS) for acidity, N and P into an integrated nutrient management system (NuMaSS);
- synthesize, analyze and assemble knowledge required to overcome recognized information gaps in the existing information base for acidity, N and P;
- test and refine NuMaSS; and
- develop auxiliary tools to facilitate use of the integrated knowledge base by a variety of users.

Outreach activities involve two major types of collaborative effort: *intensive testing areas* and an *extensive evaluation network*. Intensive testing areas are a representative region in each of three agroecological zones (semi-arid, wet-dry and humid tropics) where there is significant potential for tools developed by this project to alleviate soil acidity, N and P management problems. These three regions provide real life situations where all developmental research by the multi-disciplinary team of 16 scientists from four U.S. universities (Cornell, Hawaii, N.C. State and Texas A&M) will be conducted jointly with national and international institute collaborators. The extensive evaluation network focuses on the evaluation of products under a variety of user conditions, once suitable performance is achieved at the intensive testing areas. Although major efforts in product evaluation will occur towards the end of the 5-year project, early and continued contact with network collaborators will help ensure global relevance in product design and knowledge assembly.

Report on project tasks or activities are grouped according to the outputs or products to which they contribute; outputs and/or products are then grouped according to the stated project objective that they collectively will achieve. Progress reports are also intended to reflect a starting point for the subsequent year’s project workplan.

After submission of the annual workplans and budget for year 4, the project was notified that funding for the year would be reduced by 13%. Therefore, the project had to eliminate various planned activities for the year. Activities selected for exclusion during year 4 were selected such that the entire project was not compromised. These activities are listed in the following:

- Objective 1, output 2 - two ongoing field experiments at Cinzana, Mali were stopped;
- Objective 2, output 3 - support to IRRI’s Upland Consortium in Asia for field and laboratory data on P among trials in various countries was stopped; and
- Objective 3, output 1 - interim software releases were scaled back as was international travel to interact with and obtain feedback on software performance among members of the extensive evaluation network.

Objective 1: Develop an integrated computerized knowledge base for global use in diagnosing and recommending practical solutions to soil acidity and nutrient problems, which considers differences in resource availability and soil, climate, crop and management factors contributing to location-specific acidity and nutrient constraints.

Output 1 Integrated Nutrient Management Decision Support System (NuMaSS) Software - merge the three existing single-nutrient decision support system prototypes (acidity, nitrogen, and phosphorus) into a functional, fully integrated soil nutrient management DSS.

The three existing DSS's were programmed under different languages with different formats and structures. In order to produce a fully functioning integrated program, each individual DSS must be reprogrammed and combined with a common interface. Milestone events towards development of NuMaSS software, during the 5-year plan are as follows:

- initial NuMaSS prototype developed with each DSS reprogrammed into a common language, computer interface, and using a common database;
- intermediate NuMaSS prototype releases in years 3 and 4 with improved analytical tools and/or algorithms for integration across nutrients; integration is tested by users and necessary refinements are identified; and
- final release of NuMaSS in year 5.

Lead Investigators and Contributors:

Deanna Osmond (NCSU) coordinates the NuMaSS software development effort, with inputs from Shaw Reid (N module), Jot Smyth (acidity module) and Russell Yost (P module) through their coordination roles for the individual DSS improvement tasks. Additional contributors to this output during year 2 are listed according to their respective institutions:

University of Hawaii - Xinmin Wang and Nguyen Hue

North Carolina State University - Pedro Luna, Dan Israel, Michael Wagger

Colorado State University - Dana Hoag

Understanding Systems, Inc., Raleigh, NC - Steve Pratt, Will Branch

Progress:

Intermediate release of NuMaSS 1.5 and development for NuMaSS 2.0

1. NuMaSS version 1.5 - Based on user feedback from the Philippines workshop participants, additional changes were necessary for NuMaSS 1.0 beyond what we had anticipated for NuMaSS 2.0. As a consequence, we decided to have an intermediary release, NuMaSS 1.5. Since funding was cut and there wasn't going to be another workshop for evaluation of NuMaSS in year 4, we thought if was extremely important to ensure that any user feedback (especially feedback that we hadn't anticipated) was captured and changes made accordingly. An example of an unanticipated upgrade revolved around numerical nomenclature. Some of our users utilize a period to denote decimals while others use a comma. In order to accommodate these differences in nomenclature, we programmed NuMaSS 1.5 to accommodate both systems. These types of changes that were unforeseen in the original workplan were very time consuming but greatly aid the global transferability of NuMaSS. NuMaSS1.5, which was released in May, has these additional capabilities: the inputs for each run can be saved, retrieved and re-edited, a check against typos when entering data is provided (range check), and different keyboard configurations for decimal nomenclature can be accommodated. In addition, correction of some minor programming errors for all three

programs (ADSS, NDSS, and PDSS) were made. Approximately 140 NuMaSS 1.5 cds were distributed to collaborators, in both intensive and extensive evaluation groups. An additional 35 copies of NuMaSS 1.5 were sent to other researchers and managers both in the public and private sector.

2. <u>NuMaSS 2.0 Interface</u> - In addition to releasing NuMaSS1.5, we have made substantial progress on NuMaSS 2.0. The diagnosis portion of the interface has been reorganized and simplified based on user feedback. The interface is now much easier to navigate and fewer inputs are required. As navigation has become easier for the user, programming has become more difficult and time consuming. The interface was changed to accommodate an additional crop - peach palm. Because characteristics of peach palm are so much different from annual crops, several new input boxes have been added. The addition of these input boxes for peach palm have been iterative since we had to collect, analyze and interpret the information from the peach palm experiments before we could determine the types of questions to ask the users. We are just now finalizing information and the algorithms for peach palm in the *Diagnosis* and *Prediction* sections of NuMaSS 2.0 based on recently analyzed data.
3. <u>Images for Diagnosis</u> - We obtained over 60 slides of plant nutrient deficiencies for 9 commodities. These images are available in the diagnosis section of NuMaSS 2.0 as thumbnails. Possible nutrient deficiencies shown are N, P, K, Ca, Mg, and acidic conditions that includes Mn toxicity. If the user wants to enlarge the thumbnail, clicking on the image increases the size. These images of plant nutrient deficiencies will greatly aid the user in making correct selections in diagnosis. Authorship of the images has been fully credited. Crops and nutrient deficiencies are as follows: Corn (N, K, Ca, Mg, & P); Rice (K, N, & acidity); Sorghum (N, P, KI, Ca, Mg, & Mn toxicity); Wheat (N); Soybean (K, N, & Mn toxicity); Peanut (N, K, Ca, & Mg); Cotton (P, K, Mg & Mn toxicity); Potato (N, P, K, Mg, & Ca); Peach palm (K, Mg, N, & P); Cowpea (K & Mg).
4. <u>Agroecological Maps</u> - Based on results from the workshop and the success in dealing with nutrient management issues and concerns on an agroecological basis, we decided to use these regions to accomplish some data base queries. Using climatic maps generated by Dr. Van Wambeke of Cornell, we divided all the tropical countries into three agroecological zones: semi-arid, humid tropical, and wet/dry (Table 1). Some countries are only in one agroecolgical zone, some are in all three. Agroecological region can either be selected in the *Geography* section or by clicking on the map. We digitized the world map to allow for this method of selection.

Table 1. Agroecological zones assigned to countries in each continent for the *Geography* section of the *Diagnosis* component of NuMaSS 2.0.

Country	**Agroecosystem**
AFRICA	
Angola	semi-arid, wet/dry
Benin	wet/dry, humid tropical
Botswana	semi-arid, wet/dry
Burkina Faso	wet/dry, semi-arid
Burundi	humid tropical, wet/dry
Cameroon	semi-arid, wet/dry, humid tropical
Cape Verde	n/a

Country	Agroecosystem
Central African Republic	semi-arid, wet/dry
Central African Republic	humid tropical
Chad	semi-arid, wet/dry
Comoros	n/a
Democratic Republic of the Congo	wet/dry, humid tropical
Equitorial Guinea	humid tropical
Eritrea	semi-arid
Ethiopia	semi-arid, wet/dry
Gabon	humid tropical
Ghana	wet/dry, humid tropical
Guinea	wet/dry, humid tropical
Guinea-Bissau	wet/dry
Ivory Coast	wet/dry, humid tropical
Kenya	semi-arid, wet/dry, humid tropical
Lesotho	wet/dry
Liberia	humid tropical
Madagascar	semi-arid, wet/dry, humid tropical
Malawi	wet/dry
Mali	semi-arid, wet/dry
Mauritania	semi-arid
Mauritius	n/a
Mayotte	n/a
Mozambique	semi-arid, wet/dry
Namibia	semi-arid
Niger	semi-arid, wet/dry
Nigeria	semi-arid, wet/dry, humid tropical
Republic of the Congo	humid tropical
Reunion	n/a
Rwanda	humid tropical, wet/dry
Saint Helena	n/a
Sao Tome and Principe	n/a
Senegal	semi-arid, wet/dry
Seychelles	n/a
Sierra Leone	humid tropical
Somalia	semi-arid
South Africa	semi-arid, wet/dry
Sudan	semi-arid, wet/dry
Swaziland	wet/dry, semi-arid
Tanzania	semi-arid, wet/dry, humid tropical
The Gambia	wet/dry
Togo	wet/dry, humid tropical
Uganda	wet/dry, humid tropical
Zambia	wet/dry
Zimbabwe	wet/dry, semi-arid

Country	Agroecosystem
Central America	
Guatemala	wet/dry, humid tropical
Honduras	humid tropical, wet/dry
Nicaragua	humid tropical, wet/dry
Mexico	wet/dry, humid tropical, semi-arid
Panama	humid tropical, wet/dry
Costa Rica	humid tropical, wet/dry
El Salvador	wet/dry
Belize	humid tropical
SOUTH AMERICA	
Argentina	wet/dry, humid tropical, semi-arid
Bolivia	wet/dry, humid tropical, semi-arid
Brazil	wet/dry, humid tropical, semi-arid
Chile	wet/dry, humid tropical, semi-arid
Colombia	wet/dry, humid tropical, semi-arid
Equador	wet/dry, humid tropical, semi-arid
French Guinea	humid tropical
Guyana	humid tropical, wet/dry
Paraguay	wet/dry, humid tropical
Peru	wet/dry, humid tropical, semi-arid
Suriname	humid tropical, wet/dry
Uruguay	humid tropical, wet/dry
Venezuela	wet/dry, humid tropical, semi-arid
ASIA	
Bangladesh	humid tropical
Burma	humid tropical, wet/dry
Cambodia	humid tropical
China	wet/dry, humid tropical, semi-arid
Indonesia	humid tropical
India	wet/dry, humid tropical, semi-arid
Laos	humid tropical
Malaysia	humid tropical
Papua New Guinea	humid tropical
Philippines	humid tropical
Singapore	humid tropical
South Korea	humid tropical
Sri Lanka	wet/dry, humid tropical
Taiwan	humid tropical
Thailand	humid tropical
Vietnam	humid tropical
CARIBBEAN	
Cuba	humid tropical, wet/dry
Dominican Republic	humid tropical
Haiti	wet/dry, humid tropical

Country	Agroecosystem
Jamaica	wet/dry, semi-arid
Puerto Rico	semi-arid, humid tropical
Santa Domingo	humid tropical

5. Diagnosis Probability Values - One of the differences between PDSS and the other two modules was the use of probabilities in the diagnosis section. In order to provide a uniform and integrated system, it was necessary to develop probabilities for N deficiency and acidic conditions. Using survey information derived from our users, we developed probabilities for nitrogen deficiencies and acidic problems. These probabilities have been incorporated into the diagnostic portion of NuMaSS 2.0 (Table 2). The probability section is functioning well.

Table 2. Probability values for diagnosis of annual crops in NuMaSS 2.0.

	Probability		
Diagnostic Question	**Acidity**	**Nitrogen**	**Phosphorus**
Region			
Humid tropical	0.50	NA	NA
Semi-arid	0.45	NA	NA
Wet/Dry	0.50	NA	NA
Amazon	NA	NA	0.70
Cerrado	NA	NA	0.70
Niger	NA	NA	0.70
Mali	NA	NA	0.72
Sitiung	NA	NA	0.80
Other	NA	NA	0.50
Soil order			
Alfisols	0.57	0.74	0.50
Andisols	0.50	0.56	0.68
Aridisol	0.50	0.79	0.50
Entisols	0.58	0.68	0.51
Gelisol	0.50	0.50	0.50
Histosols	0.50	0.25	0.45
Inceptisols	0.66	0.69	0.49
Mollisols	0.50	0.65	0.37
Oxisols	0.75	0.85	0.68
Spodosols	0.50	0.90	0.47
Ultisols	0.75	0.85	0.68
Vertisols	0.50	0.66	0.50
Prev. Crop Yield/Fallow			
Forest fallow >10 yrs	0.55	0.01	NA
Forest fallow < 10 yrs	0.35	0.05	NA
[a]High yield<20Al – Crop>40Al	0.45	NA	NA
High yield<40Al – Crop>60Al	0.45	NA	NA
Savanna fallow	NA	0.20	NA

Grain legume	NA	0.45	NA
Green manure	NA	0.15	NA
Soil Analysis			
*AlSat/$AlSat_c$ > 1.5	0.75	NA	NA
*pH – pH_c < 1.0	0.75	NA	NA
Ca < 1.0 cmol kg^{-1}	0.74	NA	NA
MgSat/10 < 0.5	0.74	NA	NA
**Truoug	NA	NA	0.73
**Mehlich3	NA	NA	0.74
**Mehlich1 (1:10)	NA	NA	0.69
**Bray1	NA	NA	0.79
**Olsen	NA	NA	0.78
Crop Deficiency Symptoms (Images)			
Stubby Stunted roots (Acidity)	0.77	NA	NA
Mn toxicity (Acidity)	0.60	NA	NA
Purplish lower leaves (P)	NA	0.72	NA
Thin stalks (P)	NA	NA	0.58
Yellow leaf tip & midribs (P)	NA	NA	0.44
Yellow lower leaves (P)	NA	NA	0.43
Yellow lower leaves (N)	NA	0.70	NA
Plant Analysis			
N	NA	0.74	NA
*Ca/Ca_c<0.5	0.79	NA	NA
*Mg/Mg_c>0.5	0.77	NA	NA
*Mn/Mn_c>1.5	0.77	NA	NA
Indicator Plants			
Melastoma	0.70	NA	0.65
Molasses grass	NA	NA	0.60
Eupatorium Odoratum	NA	NA	0.51
Fern	0.70	NA	NA
Leucaena leucocefala	0.47	NA	NA

[a] High yield of a previous crop with a critical Al saturation % of 20 or less for diagnosis of a target crop with a critial Al saturation % of 40 or greater.

* Subscript “c” means critical values that will be pulled from a table for the previous crop.

** Different soil tests used for determining soil P.

In addition, a survey was developed by Jot Smyth, Russ Yost, Adrian Ares and Deanna Osmond for the probability of nutrient deficiencies and acidic problems for peach palm. The survey was sent to contacts from our extensive testing partners in Central and South America. Based on their responses, we analyzed their answers and added the probability information found in Table 3 for peach palm to NuMaSS 2.0.

Table 3. Probabilities for diagnosis of palmito in NuMaSS 2.0.

Parameter	**Probability**				
	Acidity	**Ca**	**Mg**	**N**	**P***
Soil Order					
Andisol	0.48	0.58	0.65	0.93	
Entisol	0.30	0.36	0.39	NA	
Inceptisol	0.54	NA	NA	0.73	
Oxisol	0.65	0.75	0.78	0.83	
Ultisol	0.39	0.68	0.68	0.82	
Alfisols	NA	0.45	0.45	0.50	
Other	NA	NA	NA	0.50	
Region					
Brazil (Amazon)	NA	0.73	0.78	0.83	
Brazil (Chapare)	NA	NA	NA	0.74	
Costa Rica (Atlantic)	NA	NA	NA	0.94	
Costa Rica (Pacific)	NA	NA	NA	0.90	
Other	NA	0.63	0.64	NA	
Visual Symptoms (images)					
Establishment	NA	0.69	0.67	NA	
Fast growth	NA	0.74	0.78	NA	
Mature	NA	0.74	0.78	NA	
Yellow old leaf establishment	NA	NA	NA	0.78	
Yellow old leaf fast growth	NA	NA	NA	0.80	
Yellow old leaf mature	NA	NA	NA	0.80	
Light green old leaf establishment	NA	NA	NA	0.71	
Indicator Plants					
Andropogon bicornis (Chapare only)	NA	NA	NA	0.77	
Ferns	NA	0.76	0.76		
Previous Land Use					
Palmito	NA	0.40	0.40		
Other crops**	NA	0.40	0.40		
Previous Growth					
Fast growth good	NA	0.50	0.51	0.73	
Mature growth good	NA	0.50	0.51	0.72	
Fast growth <50%	NA	0.50	0.50	0.91	
Mature < 50%	NA	0.50	0.55	0.87	
Leaf Tissue Concentration					
< 50% of critical concentration: Establishment	NA	0.63	0.63	0.87	
< 50% of critical concentration: Fast	NA	0.73	0.74	0.87	
< 50% of critical concentration: Mature	NA	0.71	0.66	0.90	
>150% of critical concentration: Est.	NA	0.37	0.37		
>150% of critical concentration: Fast	NA	0.27	0.26	0.13	
>150% of critical concentration:Mature	NA	0.29	0.34	0.10	

Parameter	Probability				
	Acidity	**Ca**	**Mg**	**N**	**P***
<150% & > 50% Establishment	NA	0.50	0.50	0.50	
<150% & > 50% Fast	NA	0.50	0.50	0.50	
<150% & > 50% Mature	NA	0.50	0.50	0.50	

* Probabilities for P not yet available
**If a previous crop other than palmito had good yields and has default % Al saturation < 40 or if humid tropics and establishment immediately preceded by slash-burn clearing of forest.

Foliar criteria in the diagnostic portion of pach palm was based on the tentative foliar critical levels for peach palm shown in the Table 4.

Table 4. Critical foliar nutrient levels used for the *diagnosis* portion of the peach palm module.

Leaf	**Ca**	**Mg**	**N**
	-------------- % ---------------		
3^{rd}	0.40	0.25	2.5
5^{th}	0.60	0.35	2.0

6. Maintenance of the project's web site - The project's web site (http://intdss.soil.ncsu.edu) continues to serve as the primary conduit for communications on project activities among U.S. and overseas participants, as well as the general public. The site's calendar section alerted all members to pending deadlines and provided advanced notification of travel schedules throughout the year. Reports on each travel event, workplans, workshops, annual progress, baseline surveys and "white papers" were produced in Acrobat Reader file format (*.pdf) and posted on the website for downloading by interested viewers. The FTP site on the project's server expedites the exchange of NuMaSS software files among programmers at N.C. State and Hawaii universities. The FTP site allowed selected users access to download NuMaSS, 1.5. Following the workshop in the Philippines an e-mail listserver was also created to facilitate continued correspondence and consultation with collaborators.
7. Initial Prototype of Nutrient Management Guidance Module (Deanna Osmond, Jot Smyth, Shaw Reid, Russell Yost and Dana Hoag) Last year we reported a second two-day working meeting was held with Dr. Dana Hoag, an agricultural economist at Colorado State University, to discuss integration of the three models within the *Guidance Section* of NuMaSS. Concurrence was reached between the four principle investigators and Dr. Hoag that the economic integration would proceed initially as a linear plateau model.
   A data set on soil characteristics, crop yields, and commodity prices was collected for the Cerrado region of Brazil. This data set was forwarded to Dr. Hoag who was able to develop a preliminary algorithm using Excel. We are verifying that the model correctly predicts fertilizer rates based on the linear-plateau model we proposed and as programmed by Dr. Hoag.
   Currently, the three nutrient DSS modules have very different input needs for the economic section. Dr. Hoag reviewed these data needs and developed a power point presentation that will serve as a reference point for developing the Economics interface in NuMaSS 2.0. An

example of the interface prototype is presented Figure 1. We identified those components most important to an integrated module: type of fertilizer selected, fertilizer cost, transportation cost, application cost, and commodity price.

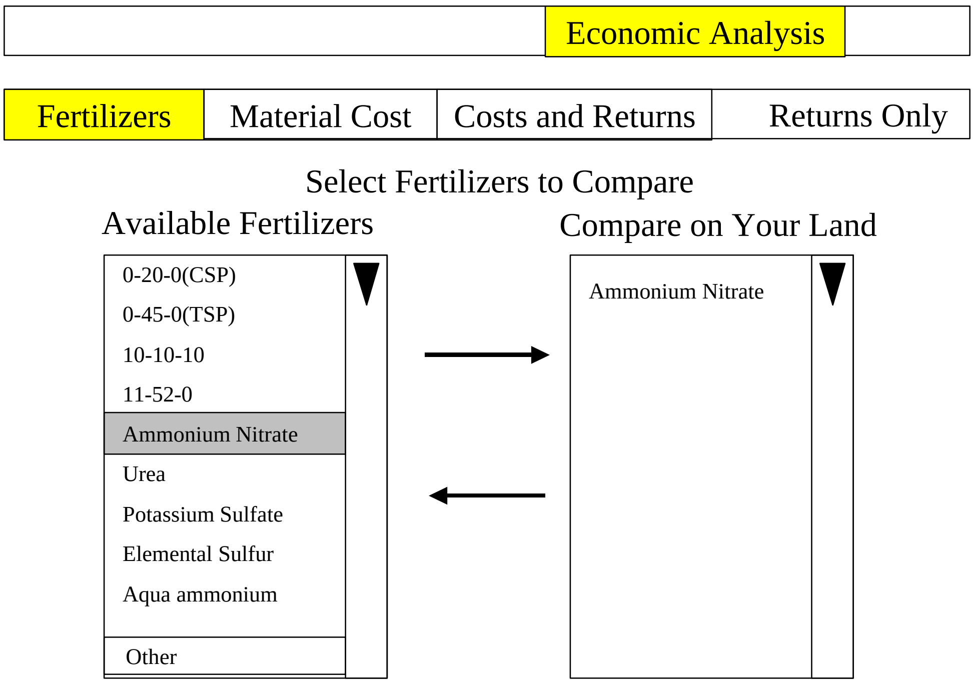

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Figure 1. Example of the interface under design for the *Economics* section of NuMaSS 2.0.

Environmental Concerns

1. Written Units (Deanna Osmond) - Information has been collected and units on the agricultural sources and affects of N and P are being written. Using N as an example, information has been collected on the N cycle, mode of transport, water quality limits, health affects, environmental affects, and agricultural sources. We have used multiple sources to collect this information. The information has been written and edited and is going through an additional review. After the review, the information will be changed into "fact sheets" and these informational units or "fact sheets" will be added to NuMaSS for release 2.0.
2. Peach Palm Work - Nitrogen losses from agricultural activities to coastal water resources is an increasing problem. Results from the suction lysimeter measurements in N fertilization experiments of peach palm production at different fertilizer rates is documenting NO_3-N losses and potential movement into ground water (See "Costa Rica" section on Output 2 of this Objective). Once this relationship between NO_3-N losses and fertilizer rates are finalized, this information will be added to NuMaSS 2.0 as a "fact sheet."

Predicting residual nutrient value

The nitrogen contribution of green manures to crop production has been incorporated into NuMaSS 1.5. The green manure information that has been collected was analyzed (see section on Output 2 of Objective 2) and N content is shown to be a function of the yield of the green manure crop. In addition, the N contribution of legumes (if stover is left in the field) has been incorporated into NuMaSS. The other residue that contributes to nutrient value that the project has reviewed is peach palm residue. Results from research reported in this report on decomposition of peach palm residue (see "Costa Rica" section on Output 2 of this Objective) is demonstrating a large release of N, P, K, Ca and Mg that continues to recycle through the system to be re-utilized by the peach palm crop.

<u>External Funding and Support</u>

None

<u>Travel and Meetings Attended</u>

Osmond, D.L. *Developing a Nutrient Management Decision Support System for the Tropics*. Cornell University, Department of Crops and Soil. Invited presentation.

<u>Relevant Publications, Reports and Presentations at Meetings</u>

Osmond, D.L., T.J. Smyth, W.S. Reid, R.S. Yost, W. Branch and X. Wang. 2000. Nutrient Management Support System, NuMaSS (Version 1.5). Soil Management Collaborative Research Support System, North Carolina State University, Raleigh, NC.

Initial Prototype of Nutrient Management Guidance Module (Power point presentation and excel spreadsheet) D. Hoag (Colorado St. Univ.) for (D.L. Osmond and T.J. Smyth (NCSU), W.S. Reid (Cornell Univ.), and R.S. Yost (Univ. of Hawaii).

Output 2 Field evaluation and refinement of NuMaSS software - testing and refining the integrated decision support system under multiple environments and agricultural systems.

The process of developing the NuMaSS software is a continuous feedback loop among developmental research and outreach activities. Upon the synthesis of existing knowledge the team gathers to formulate options and refine developmental research needs. Prototypes are tested, and the team of U.S. scientists and collaborators critique/discuss/improve the prototypes. With each repetition of this cycle the product approaches desirable performance.

NuMaSS prototype testing and evaluation will initially focus on the intensive testing areas. Once decision support products and tools achieve suitable performance in intensive testing areas, they will be evaluated and tested under a variety of user conditions throughout the extensive evaluation network. Milestone events in field evaluation and refinement of NuMaSS software, during the 5-year plan are as follows:

- team visits to Costa Rica, Mali and Philippines for selection of intensive testing sites in conjunction with host-country collaborators - year 1;
- baseline assessment of social, economic and cultural conditions, infrastructure, soil resources and nutrient management needs for each intensive testing site - year 1;
- refinement of the project's 5-year plan of research and outreach activities to ensure the particular nutrient constraints at each site are properly addressed - year 1;
- developmental field research and testing/evaluation of NuMaSS at intensive testing sites - year 2 - 5
- project impact assessment surveys at intensive testing sites - years 3 and 5; and
- feedback on evaluation of NuMaSS software and auxiliary tools from extensive evaluation network - years 2, 4 and 5.

<u>Lead Investigators and Contributors</u>

Coordination of activities at each intensive testing site was assigned to a project team-member at one of the U.S. universities. These coordinators are Jot Smyth (NCSU) for Costa Rica, Lloyd Hossner (TAMU) for Mali and Russell Yost (UH) for the Philippines. Collaborating institutions and primary contacts for each site are as follows:

Center for Agricultural Research/University of Costa Rica - Alfredo Alvarado, Raphael Salas, and Eloy Molina; Costa Rican Ministry of Agriculture/'Los Diamantes' Experiment Station - Antonio Bogantes; 'Agropecuaria Rio Frijoles' - Enrique Berrocal and Martin Sanchez;

Institute d'Economie Rurale, Mali - Mamadou Doumbia, Aminata Sidibe, Adama Bagayoko, Mamadou Diarra, Kamidou Konare (Sotuba Station); Adama Coulibaly, Oumar Coulibaly, Birama Coulibaly, Diakalia Sogodogo and Zoumana Kouyate (Cinzana Station)

Philippine Rice Research Institute/IRRI - Teodula Corton, Santiago Obien, Josephina Lasquite, Miguel Aragon and Madonna Casimero (PhilRice) and Thomas George (IRRI)

All the project's U.S. team members contribute to intensive testing site activities through their individual tasks (see Objective 2, Outputs 1-3).

<u>Progress</u>

1. *Costa Rica*

   <u>Ongoing laboratory, greenhouse and field experiments</u>

   1. Biomass and nutrient accumulation in 4- and 8-year peach palm stands - (supervised by Eloy Molina and Jimmy Boniche at UCR and Antonio Bogantes at MAG, with support from Michael Wagger and Jot Smyth) this experiment was completed during the year. The objective was to characterize seasonal distribution of annual dry matter and nutrient accumulation among harvested and recycled components of mature peach palm stands managed for heart-of-palm production. The study was performed on 4- and 8-year stands at MAG's 'Los Diamantes' Experiment Station at Guapiles. Offshoot were harvested at 4-week intervals across 52 consecutive weeks, and aboveground biomass, N, P, K, Ca and Mg was determined in materials that are exported or recycled as residue mulch.

Although there were seasonal differences in the number of offshoots harvested or pruned, the cumulative number of offshoots and biomass harvested, and their accumulated nutrient content across the 12-month period was similar for both stands. A mean total of 13.1 t ha^{-1} of dry matter was cut during the year, of which only 1.43 t ha^{-1} (11%) was removed from the field as 11,214 hearts-of-palm and protective inner stem sheaths (Table 5). Because offshoots are harvested when they achieve a specified basal stem diameter, a good relation (r^2=0.97) was obtained across all sampling dates and stands between number of harvested 'palmito' and dry weight for the sum of foliage (leaves, rachis and petioles), stem sheaths and heart-of-palm. This means that total dry weight of cut offshoots can be easily predicted in NuMaSS from user input for number of harvested palmito through multiplication by a constant value of 1.04 kg/palmito. Likewise, estimation of the recycled residues can be calculated by subtraction of the proportion of this total harvested dry matter which is exported from the field for commercial processing.

Table 5. Mean dry weights and nutrient content for shoot components of 11,214 harvested hearts-of-palm and pruned excess offshoots from 4- and 8-year peach palm stands over a 52-week period. Mean values are based on six plot replicates in each stand.

	Harvested Offshoots					
		Stem Sheaths			Pruned	
	Foliage	Outer	Inner	Heart-of-palm	Offshoots	Total
	kg ha^{-1}					
Dry Matter	8,524	2,779	789	637	416	13,145
N	129	19	5	17	7	177
P	21	8	2	4	1	36
K	114	40	11	20	7	192
Ca	31	10	3	3	1	48
Mg	17	6	1	3	1	28

Accumulation of nutrients in harvested and pruned excess offshoots was in the order of K.N>Ca>P>Mg (Table 5). Among these nutrients, however, proportions exported from the field as heart-of-palm and protective inner stem sheaths ranged from 12 to16%. Linear relations (with r^2>0.96) between nutrient accumulation and dry weight of harvested offshoots were also developed to enable prediction in NuMaSS of total nutrient content for a given level of harvested palmitos; these regressions indicate that the mean nutrient concentrations in harvested offshoots are 1.40% N, 0.27% P, 0.37% Ca, 0.21% Mg and 1.60% K.

On any given harvest date in mature peach palm stands there is a certain fraction of standing biomass which is in equilibrium with the offshoots with are ready to be harvested. This standing biomass consists of a certain number (6-9) of offshoot at different stages of development which will be harvested at future dates. We estimated the standing biomass and nutrient content by destructively sampling all plants in each plot after the final harvest at 52 weeks (Table 6).

Table 6. Mean dry weight and nutrient content of standing aboveground biomass for developing offshoots after the final harvest of heart-of-palm at 52 weeks in the 4- and 8-year peach palm stands.

Dry Matter	**N**	**P**	**K**	**Ca**	**Mg**
---------------------------------- kg ha^{-1} ----------------------------------					
5,879	72	20	92	17	12

The combination of data for harvested and standing biomass and nutrients reveals the following aspects concerning annual budgets for mature peach palm stands: 1) a total production of 19.0 t ha^{-1} of aboveground dry biomass, of which 69% is cut each year and only 8% is removed for commercial processing of heart-of-palm; 2) the order of ranking for nutrient accumulation is the same in both harvested and standing biomass - K.N>Ca>P>Mg; and 3) of the total nutrient stock in the biomass, quantities exported from the field range from 9% for N and Ca to 11% for P and K.

b. Decomposition and nutrient release from crop residues of harvested offshoots for heart-of-palm - (UCR supervision by Gabriela Soto, Eloy Molina and Jimmy Boniche with assistance from Michael Wagger, Pedro Luna and Jot Smyth) this field experiment in a 16-year commercial peach palm stand near Guapiles has the objective of characterizing the rates of decomposition and nutrient release from the large quantities of foliage which are cut with each harvested heart-of-palm and left in fields as a mulch. Fiber glass mesh bags with harvested foliage were placed on the soil surface between peach plant rows. The bags were collected at nine dates over a 48-week period and analyzed for remaining dry matter and nutrient content. There were three series of bags distributed across 48-week periods encompassing 1.5 years. Final samples were collected and prediction equations for dry matter decomposition and nutrient release were completed during this year. A preliminary description of the results and the prediction equations were described in the annual report for project year 3. There were no significant differences in foliage decomposition and nutrient release between the three 48-week periods investigated. Thus, all observations were pooled for development of prediction models. With the exception of K release which fit a single exponential model, % dry matter loss or release of other nutrients were best described by an asymptotic model.

Prediction models developed in this study were applied to harvested foliage in the previously-reported trial where palmitos were harvested at 4-week intervals across a 12 month period. Nutrient release of foliage residue mulch for each harvest was estimated for the remaining period during the 12 months and summed to derive the total annual release. Predicted annual nutrient release from foliage residue are compared in Table 7 with annual totals for nutrients in the residue pool, uptake and fertilizer inputs for the 4-year stand. Comparisons of total uptake in harvests with fertilizer inputs reveals that uptake exceeds annual applications for N, P, K and Ca. However, appreciable amounts of the annual nutrient uptake can be accounted through recycling of nutrients from the decomposition of foliage residue left in the field as a mulch. Annual release of nutrients in the foliage ranges from 67% for Ca to 96% for K. The potential needs for fertilizer inputs was estimated as the difference between total uptake in harvests and the predicted release from foliage residue. Comparisons between actual fertilizer added and potential fertilizer needs reveals that P and K fertilizer inputs match the estimated needs, whereas there may be an excess in N and Mg inputs and a draw-down of soil Ca reserves. However, these estimates assume 100% efficiency in uptake of nutrients recycled from foliage residues and do not consider uptake efficiencies for nutrients added in fertilizers.

Table 7. Comparisons between nutrients added in fertilizers, accumulated in harvested and pruned offshoots, and release from foliage residue mulch during a 12-month period in a 4-year peach palm stand.

	N	**P**	**K**	**Ca**	**Mg**
Fertilizer added (kg ha^{-1})	155	19	108	0	31
Total uptake in harvests (kg ha^{-1})	161	36	210	44	26
Foliage residue nutrients released (kg ha^{-1})	93	15	116	19	13
% Foliage residue nutrient release	81	73	96	67	85
Potential fertilizer uptake (kg ha^{-1})[a]	68	21	94	25	13

[a] Nutrient uptake in harvests - nutrients released in foliage residues

c. N fertilization field trial - (supervision by Eloy Molina, Alfredo Alvarado, Gabriela Soto, Rafael Salas, Jimmy Boniche of UCR and Antonio Bogantes of MAG with assistance from Shaw Reid, Michael Wagger, Deanna Osmond and Jot Smyth) since N is one of the major nutrient needs for mature peach palm stands and, in the absence of other field trials, an experiment was started during the year to characterize palmito yield response to fertilizer N. The experiment was started on May 22, 2000 in a 5-year stand at MAG's 'Los Diamantes' Experiment Station on a soil classified as Aquandic Dystrudepts. Selected chemical properties are shown in Table 8 for the surface 15-cm layer. Prior to starting the N experiment, the standard harvest and pruning management, and fertilization (except N) was applied to the stand to develop uniformity in the number of offshoot per plant. Fertilizer N treatments include 0, 50, 100, 200 and 400 kg ha^{-1} as NH_4NO_3 (the standard N source recommended for peach palm in Costa Rica), and 100 kg ha^{-1} as urea. In all these treatments crop residues a left in the field as mulch. In an additional zero-N treatment crop residues are removed with each harvest to provide comparisons between native soil N contributions and the crop residues. All N fertilizers and blanket rates of P, K and Mg are surface-applied in bands between plant rows as equal split-applications every 60 days. Each plot consists of four 10-m plant rows with treatments arranged in a randomized complete block design with three replications.

Table 8. Selected initial properties for the surface soil layer 0-15cm of the site for the N fertilization trial.

pH in	Olsen-Extractable			KCl-Extractable		Olsen	Al	Org.
H_2O	Ca	Mg	K	NH_4	NO_3	P	Sat.	Matter
	---------- cmol L^{-1} ----------			---------- mg L^{-1} ----------			----- % -----	
5.0	4.14	1.05	0.25	12.8	3.0	25.0	15	4.28

Cumulative palmito yields during the first 29 weeks of the experiment are shown in Figure 2. Palmito yields essentially doubled between 0 and 200 kg N ha^{-1}, but there was no additional yield increase between 200 and 400 kg N ha^{-1}. The effect of N release from crop residues was also evident by the end of the 29 weeks, where yield for the zero-N treatment with residue removal was significantly less than for the zero-N treatment where residues at each harvest are left in the field as a surface mulch. Palmito harvests will continue to be monitored at 4-

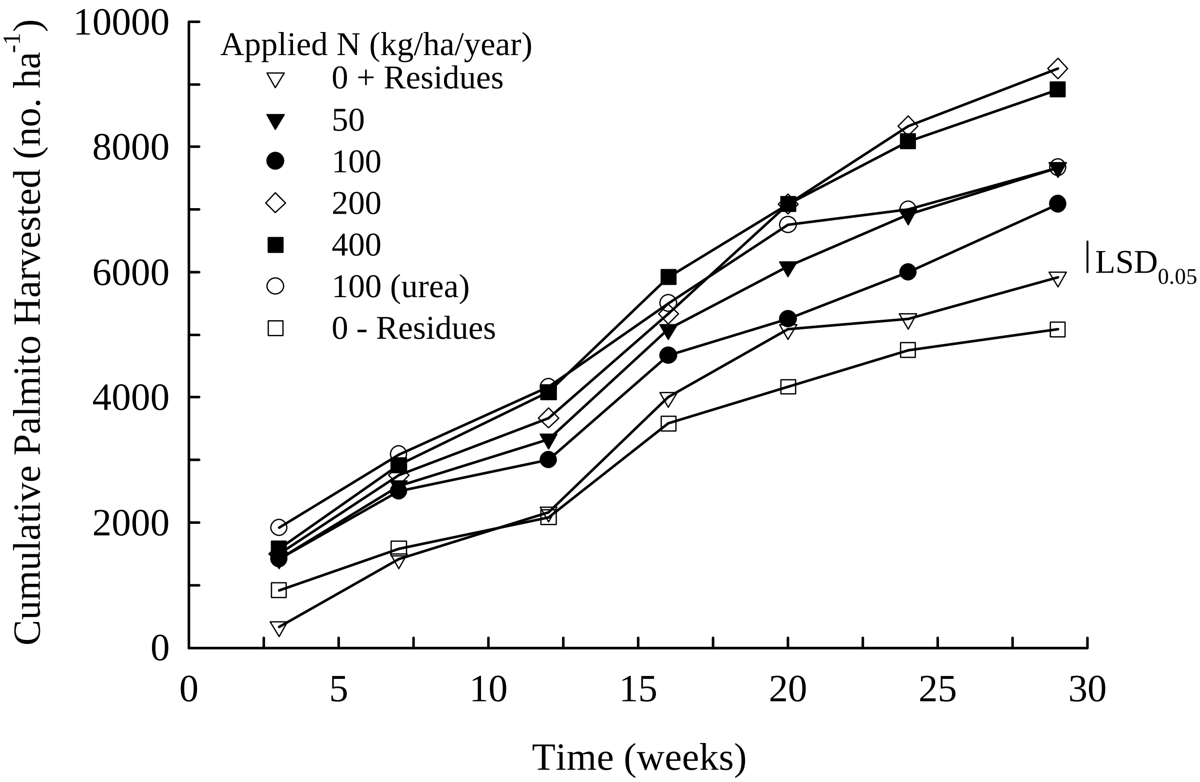

Figure 2. Cumulative heart-of-palm yield as a function of fertilizer N and residue treatments during the first 29 weeks.

week intervals for a 12-month period. Harvested plant components are being analyzed for N content in order to develop an annual N budget for each treatment. Diagnostic leaf tissue are also sampled every trimester and analyzed for N.

Suction lysimeters at three depths (5, 20 and 40 cm) are used to access N movement in three of the fertilizer N treatments. Samples are drawn during each 60-day period between fertilizer N applications and analyzed for NH_4 and NO_3. Trends in solute N distribution with time after the first surface application of fertilizer N are shown in Figure 3. Nitrogen movement to 20 cm was evident for annual N rates of both 200 and 400 kg ha^{-1} (only 33.3 and 66.6 kg ha^{-1} applied thus far) at seven days after application. Residence time of N at this intermediate depth extended to 45 days. Significant increases in solute N at 40 cm were only detected for the treatment with 400 kg N ha^{-1}, which is an N level that thus far exceeds the crop requirements for maximum palmito yield (Figure 2).

Initial project surveys revealed that some farmers were applying up to 400 kg of N ha^{-1} $year^{-1}$. If the initial results for palmito yield and N movement are sustained during continuation of this experiment, fertilizer N recommendations could be reduced with potential alleviation of N movement to groundwaters, improved efficiency of fertilizer N use, and reduced fertilizer costs.

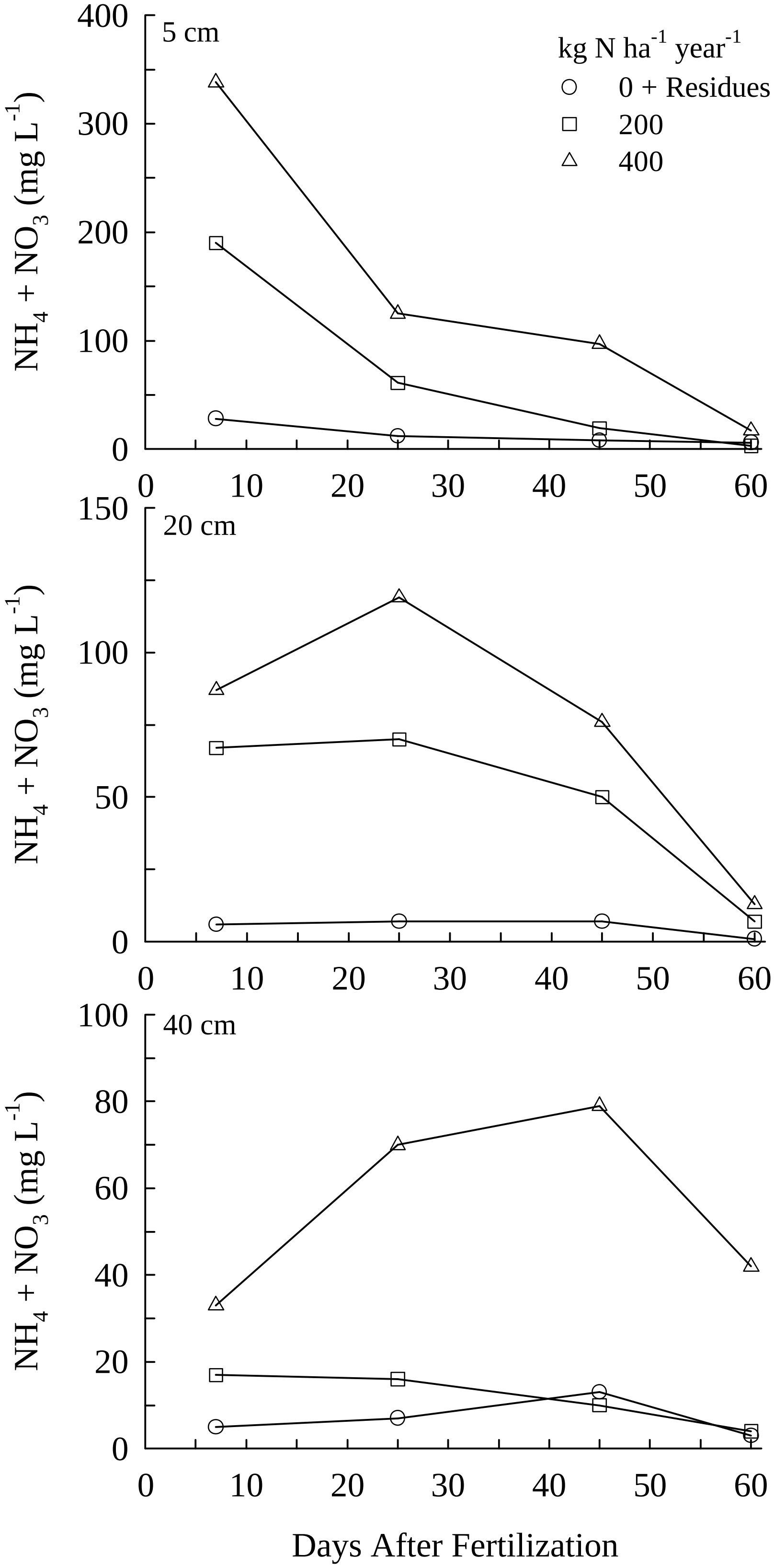

Figure 3. Ammonium and $N0_3$ distribution in suction lysimeter solutions as a function of soil depth, N treatments and time.

d. Patterns of biomass accumulation - (supervised by Eloy Molina and Jimmy Boniche at UCR with support from Adrian Ares and Russell Yost) Perennial tree crops develop through growth phases that differ in the rates of biomass and carbon build-up, and in the relative contribution of various stores to fluxes in nutrient cycles and nutrient supply for plant growth (Figure 4). To define these phases in peach palm (*Bactris gasipaes*) agroecosystems for heart-of palm production, we estimated biomass stores in stands up to 20 years old in the humid tropical lowlands of Costa Rica. Dry biomass of foliage, petioles and stems were estimated using allometric equations which were previously generated by applying nonlinear seemingly unrelated regression procedures to harvest data from of peach palm plants (Figure 5). Total aboveground biomass trajectories through time were fit to three-parameter logistic

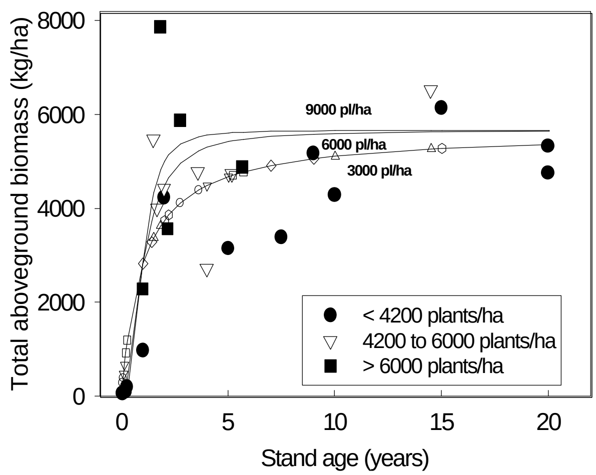

Figure 4. Standing biomass through time in peach palm stands in the Atlantic Region of Costa Rica. Curves were calculated from fitted equation and predicted values are given in the solid lines for 3000, 6000, and 9000 plants / ha.

functions with total biomass stabilizing at about 5.5 Mg/ha at age 10 in stands with less than 4200 plants/ha, and at 3-4 years in stands with more than 4200 plants/ha (Figure 4). There were no differences in aboveground biomass between stands on Andisols and Ultisols. Trends in nutrient stores through time were similar to those for biomass. Excavations of peach palm plant bases and coarse roots ('spiders') suggested that there are relatively large biomass stores and, subsequently, carbon and nutrients sequestered belowground in peach palm agroecosystems. The amount of carbon per unit area in plant tissues in peach palm agroecosystems in the Atlantic Region of Costa Rica is about 8 % of the carbon in forests of the same region.

<u>Development and validation of allometric equations, and generation of functions to predict biomass accumulation of peach palm through time for the phosphorus and nitrogen modules of NuMass</u> - We analyzed harvest data obtained in 1999 using a nonlinear seemingly unrelated procedure (NSUR) which simultaneously fits the component equations that predict

leaf, petiole and stem in order to assure biomass additivity (Figure 5). Equation coefficients for NSUR fitted-regressions that also model equal variances were substantially different from those for individual regressions which independently calculates equation coefficients (e.g., $Biomass_{leaf} = 11.47\ BD^{1.8042}$ for the individual equation versus $Biomass_{leaf} = 6.84\ BD^{2.086}$ for the NSUR fitted-equation). NSUR equations had slightly less precision in estimating biomass that individual equations but consistently less bias.

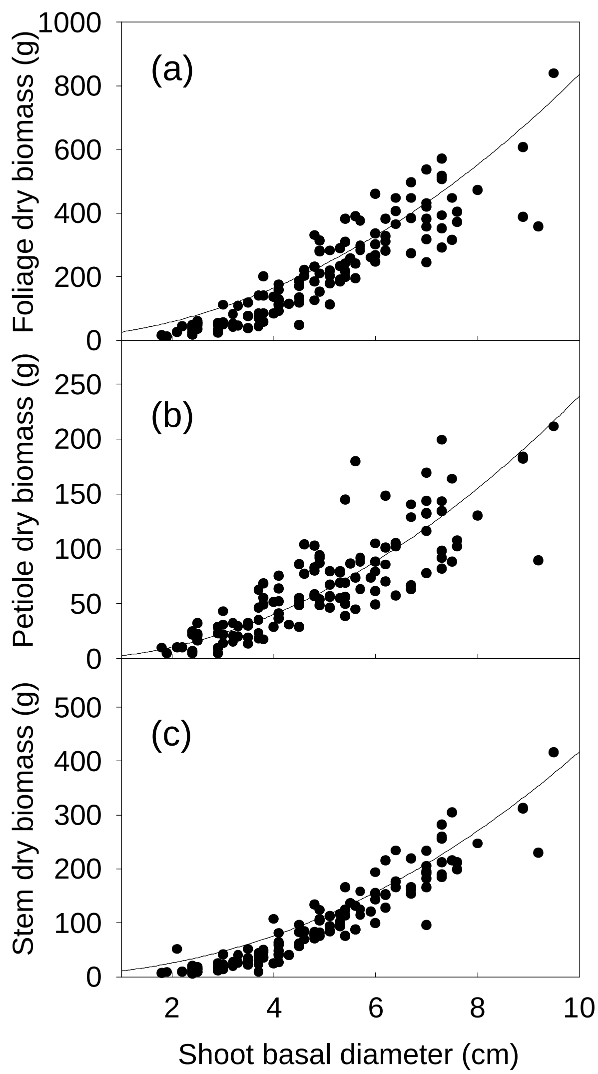

Figure 5. Relationships between shoot basal diameter and (a) foliage, (b) petiole, (c) stem dry biomass for peach palm in the Atlantic region of Costa Rica. Allometric functions derived from nonlinear seemingly unrelated regressons (NSUR) are presented by solid lines.

To validate the developed equations, we harvested peach palm plants within four stands ranging in age from 1.9 to 21 years. Estimates of component and total aboveground shoot biomass were similar to observed values except for the youngest stand in which biomass was overestimated. In another harvest, yield of heart-of-palm per plant was linearly related to total aboveground biomass in two peach palm stands of age five and nine years.

To define growth phases in peach palm, we estimated biomass in stands up to 20 years old in Costa Rica. Dry biomass of plant components were estimated using the allometric equations generated previously. Total aboveground trajectories through time were fitted by three-parameter logistic functions with total biomass stabilizing at about 5.5 Mg/ha. The order in size of nutrient pools was N (up to approximately 120 kg/ha) > K (up to 90 kg/ha) > Ca (up to 40 kg/ha) > S, P (both up to 16 kg/ha) > Mg (up to 15 kg/ha). In the examined stands, there were no significant changes with stand age in soil organic carbon, soil pH, exchangeable acidity and soil macro and micronutrients. In a mature peach palm stand on an Andisol, there is approximately 8.0 Mg C ha^{-1} in aboveground biomass and 83 Mg C ha^{-1} in the topsoil.

We also excavated the belowground biomass component in peach palm stands ranging in age from 2 to 21 years and with an initial density of 5000 plants/ha. The trajectory of the ratio of belowground to aboveground biomass through time fitted a rectangular, two-parameter hyperbola and varied between one in young stands to more than two in mature stands. On an area basis, there may be more than 10 Mg/ha of belowground biomass in a mature peach palm stand. This indicates that relatively large stores of carbon and nutrients are underground in peach palm stands.

Because of the important of the yield of hearts-of-palm, the allometric equations were examined to determined if they could be used to estimate yields of the commercial product – hearts-of-palm (Figure 6). The data indicate that, indeed, predictions of hearts-of-palm were relatively accurate and should be useful in estimating yields nondestructively.

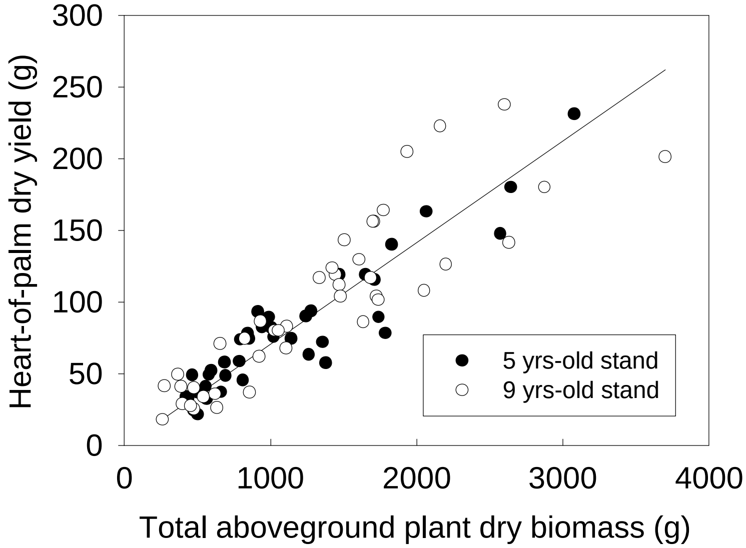

Figure 6. Relationship between total aboveground shoot biomass (SB) and heart-of-palm yields (Y) for two peach palm stands at 'Los Diamantes' Experimental Station, Costa Rica (Y = 0.0718 SB, RMS = 24, R^2_{adj} = 0.95, n=81.

Growth and nutritional response of peach palm to P additions - The experiment started on August 1999 in Altamira, Costa Rica, and described in the Year 1999 report, proceeded as scheduled during the year 2000. One-year heart of palm yields did not respond to P additions although soil levels were initially low. Foliar P levels, however, were all above proposed sufficiency levels of 0.23% for young leaves and 0.16 % for old leaves. The fertilization strategy was changed during the second year by adding the annual P doses in one application. Recent sampling indicated a relatively large gradient in soil P (from about 4 to 30 mgP/g) between the control and the high-P level but this variation does not concur with foliar P levels. Also, recent data indicated that the peach palm stand appears to show some response in yield to P additions.

In Brazil, responses to P additions were observed in experiments for heart-of-palm, however, neither foliar P (young and old leaves) nor soil P at 0-5 and 5-20 cm depths) were able to predict that a yield response would occur. For fruit production in Brazil, plants did not respond to P additions above 20 kg/ha where P foliar contents were above the proposed critical levels.

Additional diagnostic criteria for P deficiency in peach palm - Results so far indicate that whole-plant characteristics would be more useful than tissue features to characterize P deficiencies in peach palm. Soil and plant P analysis did not adequately diagnose plant P status and predict responses to P additions in peach palm. Tissue nutrient analysis on peach palm stands in Costa Rica with soil P ranging from about 7 to 40 mgP/g indicated that petiole P showed the largest variation in P concentration while foliar P exhibited the smallest change. The variation was intermediate for coarse roots and plant bases ("spider").

Additional testing should be conducted in trials where response to P additions was already detected such as the case of the Amazon region.

2. *Mali*

<u>Inorganic and organic mixtures of fertilizer materials</u> - (Mamadou D. Doumbia, Aminata Sidibe, Adama Bagayoko, Mamadou A. Diarra, Hamidou Konare, Adama Coulibaly, Birama S. Coulibaly, Diakalia Sogodogo, Zoumana Kouyate of IER with support from Richard Kablan and Russell Yost)

a. *Calibration of P Buffer Coefficients* - Laboratory incubation studies were conducted to calibrate P buffer coefficients predicted by the PDSS component of NuMaSS using selected soils of Mali . These samples were first analyzed for clay content and Bray-1 P. These data were used by PDSS to predict buffer coefficients referred to as a_{2m}. These soil samples were then incubated to estimate buffer coefficient referred to as a_{2i}. Then, a_{2m} and a_{2i} were compared. Selected data from this study is shown in Table 9.

Table 9. Clay content and P buffer coefficients of selected soils of Mali.

		P Buffer Coefficient (a_2)		
Treatments	**Clay**	**Lab Incubation**	**NuMaSS**	**Mean**
	%			
SOILS				
Cinzana summit	5.2	0.78	0.85	0.81a
Cinzana J11	18.2	0.52	0.54	0.53c
Macina - Moursi1	59.9	0.15	0.14	0.14g
Macina - Moursi2	53.8	0.19	0.17	0.17gf
Seno	4.7	0.82	0.51	0.66b
Selingue1	24.2	0.78	0.49	0.63b
Selingue2	3.6	0.14	0.89	0.50c
Dougouba	3.4	0.77	0.89	0.83a
Doubouba2	2.8	0.80	0.91	0.87a
Macina - Danga1	27.5	0.08	0.40	0.24f
Macina - Danga2	34.4	0.08	0.32	0.20f
Sdt1 Moursi	32.7	0.47	0.27	0.37c
Sdt2 Danga	24.5	0.60	0.45	0.52c
Sdt3 Danga	29.5	0.51	0.38	0.45d
Sdt4 Molodo	31.9	0.32	0.35	0.33e
METHODS				
Lab Incubation (a_{2i})				0.47b
NuMaSS (a_{2m})				0.50a
Interaction (SxM)				S
CV (%)				12

The correspondence between the laboratory incubation and predicted values is remarkable and suggests that the buffer coefficient approach has wide applicability and likely will be useful for initial predictions of P requirements for many regions in West Africa where prior soil testing has been difficult.

b. *Placement of Mineral and Organic Fertilizers*

1. Placement of mineral fertilizer -

Table 10. Sorghum yield as influenced by methods of mineral fertilizer application.

Treatment	Harvested Plants	Plant Height at Harvest	Sorghum Yield Head	Grain	Stalk
	no. /ha	m	---------- kg ha^{-1} ----------		
Check	39445a	2.27b	860b	490a	2940a
1:1 Seed-fertilizer Mix	25000a	2.41a	1370ab	930a	2890a
Seed & fertilizer same hill	25000a	2.28a	840b	600a	2500a
Conventional application	31667a	2.46a	1620a	990a	2100a
CV (%)	29	2	27	44	46

2. Placement of organic amendments -

Table 11. Sorghum yield as influenced by methods of manure application.

Treatment	Harvested Plants	Plant Height at Harvest	Sorghum Yield Head	Grain	Stalk
	no. /ha	m	---------- kg ha^{-1} ----------		
Check	19506a	2.30a	790b	600b	3090a
Plowing under	34321a	2.50a	1320a	940a	3940a
Surface placement	34691a	2.50a	900b	750ab	3930a
CV (%)	25	2	16	13	23

3. "Manure Extender" Studies - These studies involved both factorial combinations and substitutions of mineral and organic sources of nutrients. The impacts of these were evaluated on sorghum yield and soil properties.

Substitution Experiment An experiment involving substitutions of organic and mineral sources of P was planted at the Sotuba experiment station. The total P to provide was that contained in 100 kg DAP (20%)) and 5000 kg of manure (0.56%). Ratios tested were 100:0, 75:25, 50:50; 25:75, 0:100 and a check.

Table 12. Sorghum yield as influenced by substitutions of organic and mineral sources of P.

Treatment	Harvested Plants	Plant Height at Harvest	Sorghum Yield Head	Grain	Stalk
	no. /ha	m	---------- kg ha^{-1} ----------		
100:0	1.92ab	42084a	1540a	1292a	2916a
75:25	1.96a	28125ab	1380a	979b	2292ab
50:50	1.86ab	26042b	1020b	792bc	1876bc
25:75	1.74ab	39167ab	1330a	917b	1875bc
0:100	1.69b	24167b	810b	708cd	1458c
Check	1.79ab	27500ab	980b	521d	1459c
CV (%)	9	29	17	15	24

Combination Experiment A 4 x 3 factorial combination experiment was implemented at the Sotuba experiment station.

Table 13. Sorghum yield as influenced by combination of mineral and organic sources of nutrients.

Treatment	Harvested Plants	Plant Height at Harvest	Sorghum Yield Head	Grain	Stalk
	no. /ha	m	---------- kg ha^{-1} ----------		
ORGANIC SOURCE (kg ha^{-1})					
0	32222a	1.61a	1220a	430a	1430a
1250	32570a	1.66a	640b	670ab	1560a
2500	73429a	1.67a	900ab	770a	1570a
5000	25926a	1.69a	1130a	890a	1570a
MINERAL SOURCE					
0	32500a	1.63a	750a	460b	1460a
Unique R	33750a	1.68a	1090a	720a	1610a
2x Unique R	56947a	1.69a	1930a	770a	1490a
Interaction Org x Miner	NS	NS	NS	NS	NS
CV (%)	60	9	42	39	41

In the case of organic amendments it appears that plowing the organic material into the soil may be more beneficial than surface placement, a not too surprising result. Of particular interest where organic fertilizer was applied was the greater head weights, which may have been a result of better nutrient conditions during head filling than during formation of the number of heads.

The results here presented indicate no significant difference in yields among the various types of fertilizer placement. This appears to be, in part, due to unusually high variability (CV = 44%). The sister block of this experiment was far less variable (CV = 12%), and less differences between treatments were significant.

'Manure extender' results indicated less effectiveness of organic manures alone, particularly when added alone. The number of plants in the differing treatments was very large and may have been a factor in the greater yields where inorganic manures alone were used.

In the case of the combination experiments it is very difficult to infer meaningful conclusions from only yield data. Analyses of soils and plant tissues are integral parts of such research because they often provide an explanation for the effects. For example, it appears from the check plot that the initial soil levels of nutrients were relatively high, making it very difficult for the experiment to detect any effects.

<u>Completion of year-3 mid-term socio-economic assessment</u> (Mamadou Doumbia, Adama Coulibaly, Oumar Coulibaly, Lloyd Hossner, Frank Hons, Jot Smyth and Frank Smith) - during this year, all data was collected and the mid-term report was finalized. During the baseline survey in year 1, 16% of farmers in the Cinzana area reported use of 15-15-15 fertilizer and 9% reported use of urea in millet production. These results were inconsistent with local researcher experience and the unfavorable price ratios between millet and fertilizers. Table 14 shows that millet farmers using fertilizers were distributed among sampled villages, and included both landowners and farmers using land of others. Their production areas ranged from 4 to 24 ha and several application rates and methods are reported. Fertilizers were usually applied to "hot spots" (areas of pronounced nutrient and/or water deficit), instead of uniform applications to all the land cropped to millet. Farmers explained the need to invest in fertilizers to (1) compensate for farmyard manure shortages, (2) poor nutrient quality of the manures, or (3) improve yield of late plantings. Farmers using chemical fertilizers also used manures, insecticides and intercropping practices (Table 15). A survey of 1999 commodity prices in the Cinzana area revealed that millet and sorghum prices were considerably lower than the national average producer prices (latest national data was for 1998). Cinzana region and national average prices were 50 and 105 CFA/kg for millet, and 60 and 98 CFA/kg for sorghum.

Seasonal changes in prices of inputs and crops were also summarized for the Cinzana area (Table 16). While fertilizer prices are stable throughout the year, labor costs are highest during the season of land preparation. The variation in millet prices by 50% accounts for farmer efforts to store this staple for future consumption and sale.

Table 14. Descriptive information on the subset of millet farmers using chemical fertilizers.

		Land		Fertilizer			Supplementary	
Farmer	Village	Tenure	Area	Type	Dose*	Method	Dose	Method
			ha		kg ha^{-1}		kg ha^{-1}	
1	Dilaba	Landowner	10.00	CC	100	localized	0	0
2	Dougouba	Exploitant	10.00				75	broadcast
3	Dougouba	Landowner	5.00	CC	75	localized	25	localized
4	Cinzana-Village	Landowner	4.00	CC	50	broadcast	0	0
5	Cinzana-Village	Landowner	12.00	CC	100	broadcast	0	0
6	Konogola	Landowner	6.50	CC	100	localized	0	0
7	Konogola	Landowner	12.50	CC	100	localized	0	0
8	Cinzana-Gare	Exploitant	6.00	CC	50	broadcast	0	0
9	Konogola	Exploitant	24.00	CC	50	localized	50	localized
10	Konogola	Exploitant	6.00	CC	100	broadcast	50	broadcast

*Fertilizer dose was reported by farmers as the number of 50 kg bags used per ha. However, the application treatment of "hot spots" or larger areas where, for example, the planting was late. Therefore, the dose rate should not be interpreted as uniform across the production area. CC= cereal complex fertilizer, 15-15-15.

Table 15. Organic matter, other inputs and intercropping practices within the subset of farmers using chemical fertilizers.

		Organic			Other	Inter-
Farmer	Village	Inputs	Dose	Method	Inputs	cropping
			kg ha^{-1}			
1	Dilaba	manure	96	placement	seed treatment	cowpea
2	Dougouba	manure	?	placement	seed treatment	cowpea
3	Dougouba	manure	15	placement	insecticides	cowpea
4	Cinzana-Village	manure	15	broadcast	seed treatment	cowpea
5	Cinzana-Village	manure	30	broadcast	seed treatment	cowpea
6	Konogola	manure	50	broadcast	seed treatment	cowpea
7	Konogola	manure	50	broadcast	seed treatment	cowpea
8	Cinzana-Gare	manure	10	broadcast	seed treatment	pulse
9	Konogola	manure	25	broadcast	seed treatment	pulse
10	Konogola	manure	50	broadcast	seed treatment	cowpea

Table 16. Change in the price in the Cinzana area during the 1999 growing season.

Input or Crop	May – July (pre-season)	Aug. – Oct. (pre-harvest)	Dec. – Jan. (harvest)	Feb. - April (post harvest)
	---------- F CFA ----------			
Farm labor (day^{-1})	1000	850	800	750
Fertilizers (kg^{-1})				
Urea (46-0-00)*	200	200	200	200
DAP (18-46-0)*	220	220	220	220
Cereal blend (15-15-15)*	200	200	200	200
Crops (kg^{-1})				
Millet	70	100	50	60
Sorghum	80	110	60	70
Peanut	300	400	150	200
Cowpea	350	400	200	250

* (% N – P_2O_5 – K_2O)

<u>On-farm evaluation of NuMaSS soil nutrient diagnosis and recommendations</u> - (Mamadou Doumbia, Aminata Sidibe, Adama Bagayoko, Mamadou Diarra, Hamidou Konare, Adama Coulibaly, Birama Coulibaly, Diakalia Sogodogo, and Zoumana Kouyate of IER and Lloyd Hossner, Frank Hons, and Anthony Juo of Texas A&M University)On-farm studies were conducted to test the recommendations from NuMaSS against a control, the standard fertilizer recommendation of Mali (Unique R) and the 4-quadrant method suggested by van Duivenbooden et al. (1966) (Quadrant R). These tests were implemented at the Sotuba Research Station for both sorghum and maize, at Cinzana for millet and sorghum, and at Dougouba for millet. Samples were collected from experimental units for laboratory characterization (Gee and Bauder, 1986; Sparks et al., 1996) and for prediction of fertilizer application rates by the NuMaSS model. Recommendations from Quadrant R are based on nutrient uptake (N, P, and K) for yield target (van Duivenbooden et al., 1996). These uptake rates were multiplied by efficiency factors to derive the Quadrant R application rates. Applications rates of N, P, K, and lime for the different treatments are indicated in Table 17.

Table 17. Fertilizer application rates for the different recommendation methods.

	DAP		Urea		K_2SO_4		Lime	
Method	**Maize**	**Sorghum**	**Maize**	**Sorghum**	**Maize**	**Sorghum**	**Maize**	**Sorghum**
	---------- $kg\ ha^{-1}$ ----------							
Control	0	0	0	0	0	0	0	0
Quadrant R	256	65	466	204	488	80	0	0
NuMaSS	202	149	378	233	0	0	750	1800
Unique R	100	100	150	50	0	0	0	0

1. *Sorghum* - yields obtained with various fertilizer recommendations were normally higher than that of the control (Table 18). The national recommendation in Mali (Unique R) should have produced a lower yield than the other two recommendation methods because of the higher rates of nutrients recommended by both models. In addition to higher rates of N and P, NuMaSS has recommendations for lime while Quadrant R includes K. Despite a strong positive trend in plant height, head yield, and stalks yield, recommendations from NuMaSS did not yield significantly higher sorghum grain. In fact, higher rates of DAP and Urea recommended by NuMaSS (Table 17) should have resulted in a grain yield increase.

Table 18. Sorghum yield as influenced rates of N, P, K and lime as predicted by various fertilizer recommendation systems.

	Plant		Yield		
Treatment	**Density**	**Height**	**Head**	**Grain**	**Stalk**
	no./ha	cm	---------- kg ha^{-1} ----------		
Control	20741b	152b	1296a	680b	2333b
Quadrant R	28148ab	178a	1745a	1162a	5222a
NuMaSS	30370ab	190a	1869a	1397a	3074ab
Unique R	36296a	186a	1775a	1259a	3037ab
CV (%)	20	7	19	14	33

2. *Maize* - The erratic rainy season did not allow maize to mature properly at Sotuba, leading to very low and non significant differences in grain yield (Table 19). Plant height and stalk yield indicated differences due to fertilizer applications. The high variability associated with the data apparently masked a significant separation of treatment means.

Literature Cited -

Van Duivenbooden, N., C.T. DeWit, and H. Van Keulen.1996. Nitrogen, phosphorus, and potassium relations in five major cereals reviewed in respect to fertilizer recommendations using simulation modeling. Fertilizer Research. 44:37-49.

<u>Cowpea and millet yield response and interactions among N, P, and lime rates</u> - (Mamadou Doumbia, Aminata Sidibe, Adama Bagayoko, Mamadou Diarra, Hamidou Konare, Adama Coulibaly, Birama Coulibaly, Diakalia Sogodogo, and Zoumana Kouyate of IER, and Lloyd Hossner, Frank Hons and Anthony Juo of Texas A&M University and Daniel Israel of North Carolina State University) The objective of the experiment was to test predictions for N, P and lime for millet and cowpea on sandy Alfisols of the African Sahel using the NuMaSS model and to identify necessary refinements to the model. The treatments in both cowpea and millet experiments were not implemented as planned. In the "millet core experiment" N rates were not established for the millet crop in 1998; therefore, N for crop growth was derived from soil N reserves. The lack of optimum N supply probably had an impact on yield response to applied P and lime. The P variable in both the "cowpea and millet core experiments" was eliminated when P level in all plots was erroneously adjusted to100% of the amount recommended by NuMASS before the 1999 cropping season. Therefore,

Table 19. Maize yield as influenced rates of N, P, K and lime as predicted by various fertilizer recommendation systems.

	Plant		Yield		
Treatment	**Density**	**Height**	**Head**	**Grain**	**Stalk**
	no./ha	cm	---------- kg ha^{-1} ----------		
			Recommendations		
Control	64075a	111b	111b	131a	2519c
Quadrant R	67038a	161a	3092a	449a	8519a
NuMaSS	67038a	162a	1926ab	403a	6296b
Unique R	70371a	163a	1407b	440a	10222a
			Varieties		
Sotubaka	65741a	150a	2389	450a	7630
Dembany uma	68334a	149a	1404b	273a	6148b
Interaction	NS	NS	NS	NS	NS
CV (%)	12	16	56	108	23

response of various crop parameters to P could not be evaluated for the 1999 cropping season. Lime was not applied before the 1999 cropping season for either core experiment as soil pH values were at desirable levels in the respective lime treatments.

Chemical analysis of soil and plant samples were conducted by personnel at the Soil and Plant Analysis Lab (LaboSEP) at the Sotuba Station In Bamako, Mali. Chemical properties of soils for both experiments were evaluated before establishment of treatments (Tables 20 and 21). Bray I P level in soils for both core experiments was 11 mg/kg in the top 7.5 cm and decreased significantly in the 7.5 to 22.5 cm depth to 6 mg/kg. Soil pH decreased and exchangeable acidity increased with depth. Exchangeable Ca increased significantly with depth which is typical of Alfisols. Exchangeable K and Mg were relatively constant with depth.

1. *Influence of P and Lime on Yield and Biomass Production of Crops* - In the 1998 season of the "cowpea core experiment " (Table 22), P and lime treatments had no significant effect on grain, stover and total yields of the cowpea crop, however, coefficients of variation for these parameters were very high (25 to 42%). In the 1999 season grain, stover and total yields of the millet crop were not significantly affected by lime application (Table 22). Leaving the cowpea residue on the plots (N0P2L2b) after the 1998 season did not enhance grain and total yields of the subsequent millet crop in 1999. It is also evident that application of fertilizer N to the 1999 millet crop did not increase the yield significantly when adequate P and lime was applied. This implies a substantial amount of N was added to the soil by the 1998 cowpea crop from roots, nodules and leaf and petiole litter that fell from the cowpea plants during seed fill. Lack of P response in the 1999 millet crop was caused by elimination of the P

variable by application of P to all plots to increase the P level to 100% of the NuMASS recommendation.

Table 20. Chemical properties of the Haplustalfs soil at Cinzana Research Station before planting the "millet core experiment" in 1998. Since samples were taken before establishment of treatments, only the effect of sampling depth is illustrated.

Chemical property	**Sampling depth**				
	0 - 7.5 cm	**7.5-22.5 cm**	**22.5-45 cm**	**45 - 75 cm**	**$LSD_{0.05}$**
Bray 1 P, mg/kg	11.0	5.5	---	---	1.2
pH in H_2O	5.6	4.8	4.6	4.7	0.22
Exch. acidity, cMole/kg	0.49	0.44	0.65	0.60	0.11
Exch..Ca, cMole/kg	0.18	0.30	0.34	0.51	0.24
Exch. Mg, cMole/kg	0.16	0.11	0.24	0.23	0.04
Exch. K, cMole/kg	0.20	0.08	0.08	0.09	0.03
ECEC, cMole/kg	1.03	0.94	1.32	1.43	0.24
carbon %	0.36	---	---	---	—

Table 21. Chemical properties of the Haplustalfs soil at the Cinzana Research Station before planting cowpea in the "cowpea core experiment" in 1998. Since samples were taken before establishment of treatments, only the effect of sampling depth is illustrated.

Chemical property	**Sampling depth**				
	0 - 7.5 cm	**7.5-22.5 cm**	**22.5-45 cm**	**45 - 75 cm**	**$LSD_{0.05}$**
Bray 1 P, mg/kg	11.8	6.6	---	---	1.4
pH in H_2O	5.4	4.7	4.7	4.5	0.1
Exch. acidity, cMole/kg	0.62	0.60	---	---	0.15
Exch..Ca, cMole/kg	0.29	0.76	0.78	0.69	0.11
Exch. Mg, cMole/kg	0.26	0.31	0.41	0.50	0.04
Exch. K, cMole/kg	0.18	0.12	0.10	0.09	0.02
ECEC, cMole/kg	1.37	1.79	---	---	0.16
carbon %	0.23	---	---	---	—

In the 1998 season of the "millet core experiment", the high P and high lime (N0P2L2) significantly increased millet grain yield even though the crop did not receive any fertilizer N (Table 23). This indicates soil reserves of N provided sufficient N to allow response to lime and P application. Lime and P application had no significant effect on stover and total yield. Apparently, improved nutrition from lime and P application enhanced assimilate accumulation in grain at the expense of vegetative plant parts. In the 1999 season, the previous lime and P treatments had no significant effect on grain, stover and total yields of the cowpea crop (Table 23). The lack of P response in the 1999 cowpea crop was caused by elimination of the P variable by inappropriate application of P to all plots. Inoculation of cowpea with a mixture of Bradyrhizobium strains from Zimbabwe (N0P2L2)did not increase seed or total biomass yields compared to the control (N0P2L0). Apparently, the indigenous strains had sufficient nitrogen fixation to support N requirements for yield levels under these soil and environmental conditions.

Table 22. Cowpea grain, stover and total yield in the 1998 season and subsequent millet grain, stover and total yield in the 1999 season as influenced by lime, N and P treatments in the "cowpea core experiment".

----------- Cowpea - 1998 Season -----------				------------ Millet - 1999 Season -------------			
Treat-ments	**Grain yield**	**Stover yield**	**Total yield**	**Treat-ments**	**Grain yield**	**Stover yield**	**Total yield**
	---------------- kg/ha ----------------				--------------- kg/ha ----------------		
N0P0L0[a]	646	1012	1658	N0P2L0	1204	3175	4378
N0P0L2	563	1296	1859	N2P2L2	1574	4233	5807
N0P1L2	605	1642	2246	N2P2L2	1491	3703	5194
N0P2L2	745	2432	3178	N2P2L2	1693	4021	5714
N0P2L0	776	2247	3024	N2P2L0	1643	4629	6272
N0P2L1	658	1568	2226	N2P2L1	1600	4286	5885
N0P1L1	573	1481	2054	N2P2L1	1627	3836	5462
N0P2L2	678	1753	2432	N0P2L2	1481	3637	5119
N0P2L2	790	1716	2506	N1P2L2	1561	3862	5423
N0P2L2[b]	1128	1852	2980	N0P2L2[b]	1878	4456	6336
N0P1L1	557	1481	2039	N1P2L1	1336	3240	4577
$LSD_{0.05}$	NS	NS	NS		NS	NS	NS
CV %	42.2	29.1	24.7		17.2	20.0	17.7

[a] Level 0 = no application of N, P or lime; Level 1 = 50% of amount recommended by NuMaSS; Level 2 = 100% of amounts recommended by NuMaSS; during 1999 season soil P was erroneously adjusted to level 2 in all treatments. Lime was only applied prior to planting in 1998 season. Fertilizer N was not applied to the selected cowpea treatments as originally planned.

[b] The only treatment where cowpea stover was left as residue in the field.

2. *Influence of Lime and P Application on Crop N and P Accumulation* - In the "cowpea core experiment", P and lime treatments had no significant effects on N accumulation in grain, and stover of the 1998 cowpea crop or in grain and stover of the subsequent 1999 millet crop

(Table 24). The lack of measurable response to treatments in the cowpea crop was associated with high plot to plot variation in yield parameters (cv 's ranged from 26 to 49%). The millet crop in 1999 also had large plot to plot variability (cv's ranged from 22 to 34%) (Table 24). Inappropriate P applications in 1999 eliminated the P variable for the millet crop. The overall grain, stover and total N accumulation means for the 1998 cowpea crop were 30, 35 and 65 kg N/ha, respectively. The overall grain, stover and total N accumulation means for the 1999 millet crop were 22, 27 and 49 kg N/ha.

Table 23. Millet grain, stover and total yield in the 1998 season and subsequent cowpea grain, stover and total yield in the 1999 season as influenced by lime, N and P treatments in the "millet core experiment".

-----------Millet - 1998 Season -----------				------------ Cowpea - 1999 Season -------------			
Treat-ments	**Grain yield**	**Stover yield**	**Total yield**	**Treat-ments**	**Grain yield**	**Stover yield**	**Total yield**
	---------------- kg/ha ----------------				--------------- kg/ha ----------------		
N0P0L0[a]	1208	3194	4402	N0P2L0	491	1506	1997
N0P0L2	1541	3483	5025	N0P2L2	376	1246	1623
N0P1L2	1522	3847	5370	N0P2L2	503	1062	1565
N0P2L2	2310	3842	6152	N0P2L2	404	1852	2256
N0P2L0	1476	4293	5770	N0P2L0	367	1358	1725
N0P2L1	1977	4000	5976	N0P2L1	426	1741	2167
N0P1L1	1546	4316	5863	N0P2L1	416	1420	1836
N0P2L2	1824	4004	5828	N2P2L2	417	1728	2145
N0P2L2	1884	4189	6073	N0P2L2[b]	315	1408	1723
N0P1L1	1518	3633	5152	N1P2L1	355	1481	1836
$LSD_{0.05}$	511	NS	NS		NS	NS	NS
CV %	17.7	19.1	16.1		21.3	35.2	28.3

[a] Level 0 = no application of N, P or lime; Level 1 = 50% of amount recommended by NuMaSS; Level 2 = 100% of amounts recommended by NuMaSS; during 1999 season soil P was erroneously adjusted to level 2 in all treatments. Lime was only applied prior to planting in 1998 season.

[b] The only treatment inoculated with a mixture of two efficient Bradyrhizobium strains from Zimbabwe when planted to cowpea.

In the "millet core experiment", high P (P2) coupled with either lime rate (L1,L2) significantly increased N accumulation in the grain of the 1998 millet crop relative to the control (N0P0L0), but did not increase stover or total N accumulation (Table 25). Grain, stover and total N accumulation by the subsequent cowpea crop in 1999 was not significantly affected by lime. Application of N to the 1999 cowpea crop (N2P2L2) did not increase N accumulation. Apparently, N fixation capacity was not a factor limiting cowpea growth and yields. The P variable was eliminated by inappropriate application of P. Overall means for grain, stover and total N accumulation by the 1998 millet crop were 22,15 and 37kg N/ha, respectively. Overall means for grain, stover and total N accumulation by the 1999 cowpea crop were 13, 32 and 47 kg N/ha, respectively.

Table 24. Cowpea grain, stover and total N in the 1998 season and subsequent millet grain, stover and total N in the 1999 season as influenced by lime, N and P treatments in the "cowpea core experiment".

---------- Cowpea - 1998 Season ----------				----------- Millet - 1999 Season ------------			
Treat-ments	**Grain N**	**Stover N**	**Total N**	**Treat-ments**	**Grain N**	**Stover N**	**Total N**
	---------------- kg/ha ----------------				--------------- kg/ha ----------------		
N0P0L0[a]	24.7	20.3	45.3	N0P2L0	15.8	17.4	33.2
N0P0L2	22.3	27.3	50.3	N2P2L2	24.8	30.7	55.5
N0P1L2	25.0	38.7	63.3	N2P2L2	23.4	28.5	52.0
N0P2L2	31.7	45.7	78.3	N2P2L2	22.4	24.2	46.7
N0P2L0	35.3	46.7	81.7	N2P2L0	24.8	34.1	58.9
N0P2L1	29.3	35.0	64.0	N2P2L1	25.6	32.7	58.3
N0P1L1	27.3	29.7	57.0	N2P2L1	24.6	27.7	52.3
N0P2L2	29.3	37.3	66.7	N0P2L2	19.2	22.5	41.7
N0P2L2	30.7	34.0	64.7	N1P2L2	21.2	22.5	43.7
N0P2L2[b]	54.7	35.7	90.7	N0P2L2[b]	24.6	27.7	52.3
N0P1L1	21.3	29.3	50.7	N1P2L1	19.7	25.0	44.7
$LSD_{0.05}$	NS	NS	NS		NS	NS	NS
CV %	49.5	37.1	25.8		21.9	34.3	25.9

[a] Level 0 = no application of N, P or lime; Level 1 = 50% of amount recommended by NuMaSS; Level 2 = 100% of amounts recommended by NuMaSS; during 1999 season soil P was erroneously adjusted to level 2 in all treatments. Lime was only applied prior to planting in 1998 season. Fertilizer N was not applied to the selected cowpea treatments as originally planned.

[b] The only treatment where cowpea stover was left as residue in the field.

Inferences about the amount of N fixed symbiotically by the cowpea crop can be derived from comparisons of total N accumulated in the 1998 millet crop of the "millet core experiment" and the 1998 cowpea crop of the "cowpea core experiment". These experiments were initiated on different parts of the same field that had been in fallow for several years. Since the millet crop did not receive the planned N application, N accumulation in the crop is a measure of residual N in the soil. As a result subtraction of total N accumulated by the millet crop from total N accumulated by the cowpea crop provides a reasonable estimate of the amount of N fixed by the cowpea crop. The overall mean for total N accumulated by the 1998 millet crop is 37 kg N/ha and the overall mean for total N accumulation in the 1998 cowpea crop is 65 kg N/ha (derived from Tables 24 and 25). Therefore, N difference indicates that the 1998 cowpea crop derived 28 kg N/ha or 43% of its N from symbiotic nitrogen fixation. Such comparisons are not feasible with the 1999 crops because the cowpea crop followed a millet crop that would have depleted soil N reserves because it did not receive N fertilizer.

Table 25. Millet grain, stover and total N in the 1998 season and subsequent cowpea grain, stover and total N in the 1999 season as influenced by lime, N and P treatments in the "millet core experiment".

----------Millet - 1998 Season ----------				----------- Cowpea - 1999 Season ------------			
Treat-ments	**Grain N**	**Stover N**	**Total N**	**Treat-ments**	**Grain N**	**Stover N**	**Total N**
	---------------- kg/ha ----------------				--------------- kg/ha ----------------		
N0P0L0[a]	16.7	12.7	29.4	N0P2L0	16.3	33.3	49.6
N0P0L2	20.3	11.7	32.0	N0P2L2	12.0	26.0	38.0
N0P1L2	21.7	11.3	33.0	N0P2L2	16.3	23.0	39.3
N0P2L2	30.7	15.3	46.0	N0P2L2	13.3	39.7	53.0
N0P2L0	19.3	16.0	35.3	N0P2L0	11.7	30.0	41.7
N0P2L1	27.0	14.3	41.3	N0P2L1	13.7	34.0	47.7
N0P1L1	21.0	17.0	38.0	N0P2L1	13.7	30.0	43.7
N0P2L2	23.3	12.3	35.6	N2P2L2	13.7	37.0	50.7
N0P2L2	24.3	22.0	46.3	N0P2L2[b]	10.3	30.7	41.0
N0P1L1	19.3	14.3	33.6	N1P2L1	11.3	30.7	42.0
$LSD_{0.05}$	7.5	NS	NS		NS	NS	NS
CV %	19.6	33.2	19.8		22.2	38.1	27.8

[a] Level 0 = no application of N, P or lime; Level 1 = 50% of amount recommended by NuMaSS; Level 2 = 100% of amounts recommended by NuMaSS; during 1999 season soil P was erroneously adjusted to level 2 in all treatments. Lime was only applied prior to planting in 1998 season.

[b] The only treatment inoculated with a mixture of two efficient Bradyrhizobium strains from Zimbabwe when planted to cowpea

The P and lime treatments did not influence P accumulation in the crops of the "cowpea core experiment" (Table 26). The high P level significantly increased total P accumulation by the millet crop in the "millet core experiment" but not significantly increase P accumulation by the cowpea crop (Table 27).

The influence of P and lime treatments on N and P concentrations in cowpea and millet crops of the cowpea and millet core experiments is illustrated in Tables 28 and 29. Lime and P treatments had no significant effect on N or P concentrations in tissues of cowpea and millet crops in either core experiment. The N concentrations in grain of the 1998 cowpea crop was 25% higher than that of the 1999 cowpea crop There is no obvious explanation for the difference.

Table 26. Cowpea grain, stover and total P in the 1998 season and subsequent millet grain, stover and total P in the 1999 season as influenced by lime, N and P treatments in the “cowpea core experiment”.

----------- Cowpea - 1998 Season -----------				**------------ Millet - 1999 Season -------------**			
Treat-ments	**Grain P**	**Stover P**	**Total P**	**Treat-ments**	**Grain P**	**Stover P**	**Total P**
	---------------- kg/ha ----------------				--------------- kg/ha ----------------		
N0P0L0[a]	2.6	1.7	4.2	N0P2L0	3.6	1.9	5.5
N0P0L2	2.3	2.5	4.8	N2P2L2	4.8	1.8	6.6
N0P1L2	2.8	3.5	6.3	N2P2L2	4.7	2.2	7.0
N0P2L2	3.9	4.7	8.6	N2P2L2	5.4	4.0	9.4
N0P2L0	4.3	4.5	8.8	N2P2L0	5.2	3.0	8.2
N0P2L1	3.2	3.0	6.1	N2P2L1	4.9	3.1	7.9
N0P1L1	3.0	2.5	5.4	N2P2L1	4.9	2.7	7.6
N0P2L2	3.5	3.7	7.2	N0P2L2	5.0	3.1	8.1
N0P2L2	4.0	3.3	7.2	N1P2L2	5.2	3.2	8.4
N0P2L2[b]	5.9	3.2	9.1	N0P2L2[b]	5.9	4.1	10.0
N0P1L1	2.6	2.8	5.4	N1P2L1	4.2	1.9	6.1
$LSD_{0.05}$	NS	NS	NS		NS	NS	NS
CV %	48.4	39.1	29.1		31.8	42.9	24.1

[a] Level 0 = no application of N, P or lime; Level 1 = 50% of amount recommended by NuMaSS; Level 2 = 100% of amounts recommended by NuMaSS; during 1999 season soil P was erroneously adjusted to level 2 in all treatments. Lime was only applied prior to planting in 1998 season. Fertilizer N was not applied to the selected cowpea treatments as originally planned.

[b] The only treatment where cowpea stover was left as residue in the field.

Table 27. Millet grain, stover and total P in the 1998 season and subsequent cowpea grain, stover and total P in the 1999 season as influenced by lime, N and P treatments in the "millet core experiment".

-----------Millet - 1998 Season -----------				------------ Cowpea - 1999 Season -------------			
Treat-ments	**Grain P**	**Stover P**	**Total P**	**Treat-ments**	**Grain P**	**Stover P**	**Total P**
	---------------- kg/ha ----------------				--------------- kg/ha ----------------		
N0P0L0[a]	3.4	2.0	5.4	N0P2L0	2.2	3.8	6.0
N0P0L2	4.9	1.4	6.3	N0P2L2	1.8	3.8	5.6
N0P1L2	4.5	1.8	6.3	N0P2L2	2.3	3.2	5.5
N0P2L2	7.0	3.2	10.2	N0P2L2	2.0	5.5	7.5
N0P2L0	4.4	2.3	6.7	N0P2L0	1.6	3.5	5.1
N0P2L1	6.2	2.7	8.9	N0P2L1	2.0	4.8	6.8
N0P1L1	4.5	4.0	8.5	N0P2L1	2.0	4.1	6.1
N0P2L2	5.6	2.5	8.1	N2P2L2	2.0	6.1	8.1
N0P2L2	9.0	3.5	12.6	N0P2L2[b]	1.6	5.2	6.8
N0P1L1	4.7	2.5	7.2	N1P2L1	1.6	4.0	5.6
$LSD_{0.05}$	NS	NS	4.2		NS	NS	NS
CV %	35.3	46.1	30.3		22.4	38.5	28.7

[a] Level 0 = no application of N, P or lime; Level 1 = 50% of amount recommended by NuMaSS; Level 2 = 100% of amounts recommended by NuMaSS; during 1999 season soil P was erroneously adjusted to level 2 in all treatments. Lime was only applied prior to planting in 1998 season.

[b] The only treatment inoculated with a mixture of two efficient Bradyrhizobium strains from Zimbabwe when planted to cowpea

Table 28. Cowpea grain and stover N and P concentration in the 1998 season and subsequent millet grain and stover N and P concentration in the 1999 season as influenced by lime, N and P treatments in the “cowpea core experiment”.

-----------------Cowpea - 1998 Season -----------------					--------------------- Millet - 1999 Season ------------------				
Treat-ments	**Grain N conc.**	**Grain P conc.**	**Stover N conc.**	**Stover P conc.**	**Treat-ments**	**Grain N conc.**	**Grain P conc.**	**Stover N conc.**	**Stover P conc.**
	--------------- % of dry wt. ---------------					----------------- % of dry wt. ---------------			
N0P0L0a	3.89	0.40	1.98	0.16	N0P2L0	1.32	0.30	0.56	0.06
N0P0L2	4.00	.041	2.30	0.20	N2P2L2	1.58	0.30	0.74	0.04
N0P1L2	4.06	0.46	2.35	0.22	N2P2L2	1.57	0.32	0.76	0.06
N0P2L2	4.23	0.51	1.89	0.19	N2P2L2	1.32	0.32	0.60	0.10
N0P2L0	4.37	0.53	2.02	0.19	N2P2L0	1.51	0.31	0.73	0.06
N0P2L1	4.60	0.49	2.22	0.18	N2P2L1	1.60	0.30	0.78	0.07
N0P1L1	4.51	0.49	2.05	0.17	N2P2L1	1.50	0.30	0.70	0.07
N0P2L2	4.13	0.50	2.10	0.21	N0P2L2	1.30	0.34	0.66	0.09
N0P2L2	3.87	0.51	2.00	0.19	N1P2L2	1.35	0.34	0.57	0.08
N0P2L2b	4.95	0.53	1.90	0.16	N0P2L2b	1.32	0.31	0.68	0.09
N0P1L1	3.89	0.45	1.99	0.19	N1P2L1	1.45	0.31	0.74	0.06
LSD0.05	NS	NS	NS	NS		NS	NS	NS	NS
CV %	15.3	11.7	19.9	23.7		10.8	7.7	35.9	38.3

a Level 0 = no application of N, P or lime; Level 1 = 50% of amount recommended by NuMaSS; Level 2 = 100% of amounts recommended by NuMaSS; during 1999 season soil P was erroneously adjusted to level 2 in all treatments. Lime was only applied prior to planting in 1998 season. Fertilizer N was not applied to the selected cowpea treatments as originally planned.

b The only treatment where cowpea stover was left as residue in the field.

Table 29. Millet grain and stover N and P concentration in the 1998 season and subsequent cowpea grain and stover N and P concentration in the 1999 season as influenced by lime, N and P treatments in the “millet core experiment”.

Millet - 1998 Season					**Cowpea - 1999 Season**				
Treat-ments	**Grain N conc.**	**Grain P conc.**	**Stover N conc.**	**Stover P conc.**	**Treat-ments**	**Grain N conc.**	**Grain P conc.**	**Stover N conc.**	**Stover P conc.**
	% of dry wt.					% of dry wt.			
N0P0L0a	1.37	0.28	0.40	0.06	N0P2L0	3.31	0.45	2.11	0.23
N0P0L2	1.33	0.32	0.33	0.04	N0P2L2	3.21	0.46	2.09	0.30
N0P1L2	1.37	0.29	0.31	0.05	N0P2L2	3.21	0.45	2.17	0.30
N0P2L2	1.30	0.30	0.40	0.09	N0P2L2	3.33	0.49	2.10	0.30
N0P2L0	1.27	0.30	0.37	0.05	N0P2L0	3.18	0.44	2.17	0.26
N0P2L1	1.36	0.31	0.36	0.07	N0P2L1	3.26	0.47	2.00	0.28
N0P1L1	1.33	0.29	0.39	0.09	N0P2L1	3.31	0.48	2.13	0.29
N0P2L2	1.33	0.31	0.31	0.06	N2P2L2	3.29	0.49	2.16	0.34
N0P2L2	1.27	0.48	0.52	0.08	N0P2L2b	3.34	0.50	2.20	0.37
N0P1L1	1.27	0.31	0.40	0.07	N1P2L1	3.20	0.46	2.07	0.28
LSD0.05	NS	NS	NS	NS		NS	NS	NS	NS
CV %	8.1	28.7	24.3	40.6		2.2	3.1	9.4	14.3

a Level 0 = no application of N, P or lime; Level 1 = 50% of amount recommended by NuMaSS; Level 2 = 100% of amounts recommended by NuMaSS; during 1999 season soil P was erroneously adjusted to level 2 in all treatments. Lime was only applied prior to planting in 1998 season.

b The only treatment inoculated with a mixture of two efficient Bradyrhizobium strains from Zimbabwe when planted to cowpea

3. *Philippines*

<u>On-farm experiments to test diagnostic predictions and compare decision-aid predictions of nutrient requirements</u>

(Thomas George, Teodula Corton, Josephina Lasquite and Russell Yost) the objectives of these on-farm trials were to test the nutrient decision-aids to determine whether they optimally diagnose and detect nutrient-responsive conditions and to document farmer diagnostic practices and crop management to improve diagnosis and prediction by NuMaSS. The on-farm testing continued on corn in 8 farms at the Ilagan project site and was expanded to Arakan valley in Mindanao on upland rice. Similar protocol as in Ilagan was implemented in Arakan on 17 cooperator farms. Plant analyses for 1999 trials were completed and available data from both 1999 and 2000 are reported here.

a. *Diagnosis and assessment of accuracy* - Site and soil properties of upland rice and corn farms in Ilagan and Arakan Valley in 1999 and 2000 are presented in Tables 30 through 33. For all crops and at both sites, NuMaSS diagnosed P and N deficiency in a majority of the farms and acidity as a constraint in only some farms. NuMaSS diagnoses and observed responses for the various crops and sites are summarized in Tables 34 through 37. Given that there were no replications for observed responses in each farm, a minimum 500 kg ha^{-1} increase in grain yield of upland rice and 1 t ha^{-1} increase in grain yield of corn in the NuMaSS treatment compared to the control treatment of zero input was recorded as a positive response. Note that while diagnoses were done for individual nutrient constraints, responses were measured for the combined application of the deficient nutrients. Kappa statistics were calculated to determine the agreement between the diagnoses and field observed responses. A Kappa value of 1 would indicate that diagnoses and field observed responses always matched. A Kappa value of 0 would indicate that there were an equal number of correct and incorrect diagnoses. The Kappa values for the various crops and sites varied from 0.85 to 1 indicating high accuracy in NuMaSS diagnoses, i.e., there was almost always an agreement between responses to combined application of N, P and lime when any one or all of them were diagnosed to be deficient.

b. *Prediction and testing of prediction* - Four treatments were implemented in 13 upland rice farms and 15 corn farms in Ilagan in 1999: 1) control (no NPK or lime), 2) farmer practice, 3) regional recommendation and 4) NuMass recommendation. A NuMaSS + K treatment was added for experiments in 8 corn farms in Ilagan in 2000 and in 17 upland rice farms in Arakan Valley in 2000. Since K applied in various amounts by farmers and is part of the regional recommendation but not considered by NuMaSS, NuMaSS + K treatment was included to test whether this element limited yield.

1. <u>1999 upland rice , Ilagan, Isabella</u> - The farmer practice in the Ilagan 1999 upland rice trial varied widely in NPK use ranging in kg ha^{-1} from 0-134 for N, 0-18 for P and 0-35 for K; thus, some farmers were exceeding both regional and NuMaSS recommendations. Because of the observed wide variation in NPK rates across treatments, the NPK application levels were grouped in several classes and were assigned new NPK treatment designations (Table 38).

The new data set with the new NPK level designations were then subjected to cluster analysis. The data clustered only with respect to N and indicated that K was not a significant factor influencing yield. Nitrogen clusters were, N1 = 9-40 kg ha^{-1} and N2 = 60-138 kg ha^{-1}.

Table 30. Site and soil characteristics of farms, upland rice, Ilagan, Isabella, Philippines, 1999.

Site	**Area**	**Slope**	**pH**	**Clay**	**Acidity**	**Al**	**Mehlich 1 P**	**K**	**Ca**	**Mg**	**ECEC**
	ha	%		%	cmol kg^{-1}		mg kg^{-1}	------------- cmol kg^{-1} -------------			
1	0.50	8-16	4.06	35	1.87	1.74	0.60		1.93	2.10	5.90
3	0.75	8-16	3.90	45	2.66	2.58	1.01		1.28	1.26	5.22
9a	0.70	0-8	4.45	35	1.69	1.75	1.60	0.01	0.22	0.80	4.23
9b	0.70	0-8	4.45	35	1.69	1.75	1.40	0.04	0.22	0.80	2.75
12	0.25	0-8	3.81	40	1.45	1.37	1.46		1.50	1.10	3.05
13 a	0.75	0-8	4.95	35	1.49	0.76	*3.23**	0.02	1.46	1.38	4.35
13b	0.50	8-16	4.62	35	1.21	1.05	*3.23**	0.02	1.46	1.38	4.07
22c	0.75	8-16	4.61	35	1.59	1.72	1.60	0.01	2.93	1.38	5.91
31	0.50	8-16	3.81	40	1.45	1.37	1.46		1.56	1.00	4.01
32	0.50	0-8	3.72	42	2.19	2.06	2.32		1.07	1.07	4.33
53	0.40	0-8	4.05	37	1.75	1.69	1.40	0.02	0.42	0.80	2.99
57	0.50	0-8	3.89	41	1.60	1.59	1.36	0.02	0.39	0.60	2.61
58	0.30	0-8	4.43	35	1.37	1.37	*4.24**	0.02	1.46	1.38	4.23

*Olsen P

Table 31. Site and soil characteristics of farms, corn, Ilagan, Isabella, Philippines, 1999

Site	Area	Slope	pH	Clay	Acidity	Al	Mehlich1 P	K	Ca	Mg	ECEC
	ha	%		%	cmol kg^{-1}		mg kg^{-1}	------------- cmol kg^{-1} -------------			
5	0.50	8-16	3.70	39	2.65	2.42	1.60		0.66	0.48	3.79
9	0.75	0-8	3.7	39	2.65	2.42	1.60		0.66	0.48	3.79
16	0.50	0-8	4.12	41	1.79	1.79	1.63	1.05	0.23	0.06	3.13
17A	0.70	8-16	4.12	41	1.79	1.79	1.63	1.05	0.23	0.66	3.13
19	0.25	0-8	4.16	40	2.16	2.0	2.24	0.98	0.30	0.04	3.49
20A	0.50	0-8	4.76	35	0.40	0.35	*15.40**	1.02	1.52	1.01	3.95
22D	0.25	8-16	5.01	35	1.20	0.98	*35.03**	0.02	0.44	0.66	2.32
24B	0.25	8-16	5.01	35	1.18	1.12	*35.03**	0.22	0.23	0.04	1.67
27	0.50	8-16	4.89	35	0.67	0.41	*8.22**	0.20	0.30	0.02	1.19
28	0.50	8-16	4.16	42	2.10	2.0	2.24	0.98	0.30	0.04	3.49
29	0.50	8-16	4.12	41	1.79	1.79	1.63	1.05	0.23	0.06	3.13
30	1.0	8-16	4.93	35	.75	0.52	*8.20**	0.92	0.22	0.04	1.93
41	0.35	0-8	4.12	41	1.79	1.79	1.63	1.05	0.23	0.06	3.49
47	0.25	0-8	4.16	42	2.16	2.0	2.24	0.98	0.30	0.04	3.49
51D	1.0	0-8	4.89	35	0.67	0.52	*8.20**	0.22	1.56	1.10	4.24

*Olsen P

Table 32. Site and soil characteristics of farms, corn, Ilagan, Isabella, Philippines, 2000.

Site	Area	Slope	pH	Clay	Acidity	Al	Mehlich1 P	K	Ca	Mg	ECEC
	ha	%		%	cmol kg^{-1}		mg kg^{-1}	-------------- cmol kg^{-1} --------------			
3	0.50	8-16	5.25	35	0.26	0.14	1.09	0.18	4.04	3.09	17.57
4	0.20	0-8	5.17	35	0.15	0.8	1.08	0.52	5.54	17.94	24.15
6	0.50	8-16	4.61	35	0.54	0.41	1.34	0.10	4.83	13.34	18.8
8b	0.50	8-16	4.38	35	1.89	1.76	5.07	0.41	3.67	9.46	15.43
9	1.0	8-16	4.46	35	1.06	0.87	3.93	0.45	6.52	17.0	25.03
16	1.0	0-8	4.4	35	0.66	0.51	3.42	0.27	2.89	8.41	12.23
21b	0.75	8-16	4.27	35	5.11	4.94	2.12	0.30	7.45	23.81	36.67
17	0.50	0-8	4.52	35	1.58	1.48	2.55	0.14	1.02	4.80	7.55

Table 33. Site and soil characteristics of farms, upland rice, Arakan Valley, Philippines, 2000

Farm	Slope	pH	Soil Texture	Acidity	Al	Mehlich1 P	K	Ca	Mg	ECEC
	%			cmol kg^{-1}		mg kg^{-1}	-------------- cmol kg^{-1} --------------			
GI1	0-8	4.54	Loamy	0.39	0.11	1.29	0.41	5.79	18.01	24.60
GI2	8-16	4.98	Loamy	0.63	0.23	2.19	0.68	22.4	21.7	45.41
GI3	0-8	4.91	Loamy	0.035	0.12	1.5	0.56	22.31	24.56	47.79
GI5*										
GI7	0-8	5.24	Loamy	0.24	0.07	4.59	0.54	14.56	27.46	42.80
GI8	8-16	5.24	Loamy	0.24	0.07	4.59	0.54	14.56	27.46	42.80
DN9	8-16	5.70	Loamy	0.13	0.02	54.41#	1.13	19.66	26.55	47.48
DN11	0-8	4.64	Loamy	0.66	0.22	1.58	0.48	10.35	26.83	38.32
DN12	8-16	5.10	Loamy	0.68	0.21	3.84	0.50	22.59	21.72	45.49
TC14	8-16	5.43	Loamy	0.21	0.07	3.53	0.67	18.81	24.7	44.40
SS15	8-16	4.58	Loamy	0.37	0.13	8.76	0.10	27.77	7.43	35.43
GB16	8-16	4.65	Loamy	0.69	0.14	8.27	0.15	28.71	7.57	36.57
ES18	0-8	5.65	Loamy	0.06	0.02	20.2#	0.09	21.32	8.34	29.77
SD19	0-8	5.17	Loamy	0.12	0.04	12.84#	0.08	19.96	6.61	36.69
JD20	0-8	5.03	Loamy	0.11	0.03	5.36	0.12	18.90	4.90	23.95
RB21	0-8	4.94	Loamy	0.12	0.04	14.5#	0.11	20.83	7.03	27.56
JM22	0-8	4.64	Loamy	0.20	0.09	4.02	0.14	17.39	4.37	21.99

*Soil properties not available.

Olsen P

Table 34. Assessing the accuracy of diagnosis, upland rice, Ilagan, Isabella, Philippines, 1999.

Diagnosis		Input	Farm												
			1	3	9a	9b	12	13a	13b	22c	31	32	53	57	58
Response	Pred.	N	+	+	+	+	+	+	+	+	+	+	+	+	+
		P	+	+	+	+	+	+	+	+	+	+	+	+	+
		Lime	-	+	-	-	+	+	+	-	+	+	-	+	+
	Obs. *	N+P+Lime	+#	+	+	+	+	-#	-	+	+	+	+	+	+
Kappa coefficient=0.85, n=13															

*Observed response is to any or all of the deficiencies diagnosed.
#An increase in grain yield of at least 500 kg ha^{-1} in the NuMaSS treatment compared to the zero input control is arbitrarily set as a positive response.

Table 35. Assessing the accuracy of diagnosis, corn, Ilagan, Isabella, Philippines, 1999.

Diagnosis		Input	Farm														
			5	9	16	17a	19	20a	22d	24b	27	28	29	30	41	47	51d
Response	Pred.	N	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
		P	+	+	+	+	-	-	+	+	+	+	+	+	+	+	-
		Lime	-	-	+	+	-	-	+	+	-	+	-	+	+	+	-
	Obs. *	N+P+Lime	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Kappa coefficient=1, n=15																	

*Observed response is to any or all of the deficiencies diagnosed.
An increase in grain yield of at least 1 t ha^{-1} in the NuMaSS treatment compared to the zero input control is arbitrarily set as a positive response.

Table 36. Assessing the accuracy of diagnosis, corn, Ilagan, Isabella, Philippines, 2000.

Diagnosis		**Input**	**Farm**							
			3	**4**	**6**	**8b**	**9**	**16**	**21a**	**17**
Response	Pred.	N	+	+	+	+	+	+	+	+
		P	+	+	+	+	+	+	+	+
		Lime	-	-	-	-	-	-	-	-
	Obs. *	N+P+Lime	+	+	+	+	+	+	+	+
Kappa coefficient=1, n=8										

*Observed response is to any or all of the deficiencies diagnosed.
An increase in grain yield of at least 1 t ha^{-1} in the NuMaSS treatment compared to the zero input control is arbitrarily set as a positive response.

Table 37. Assessing the accuracy of diagnosis, upland rice, Arakan Valley, Philippines, 2000.

Farm	**Diagnosis**			**Observed response***
	N	**P**	**Lime**	
GI1	+	+	-	+[#]
GI2	+	+	-	+
GI3	+	+	-	+
GI5	+	+	-	+
GI7	+	+	-	+
GI 8	+	+	-	+
DN9	+	-	-	+
DN11	+	+	-	+
DN12	+	+	-	+
TC14	+	+	-	+
SS15	+	+	-	+
GB16	+	+	-	+
ES 18	+	+	-	+
SD19	+	+	-	+
JD20	+	+	-	+
RB21	+	+	-	+
JM22	+	+	-	+
Kappa coefficient=1, n=17				

*Observed response is to any or all of the deficiencies diagnosed.
[#] An increase in grain yield of at least 500 kg ha^{-1} in the NuMaSS treatment compared to the zero input control is arbitrarily set as a positive response.

Table 38. Range of NPK amounts applied to upland rice in on farm trails at Ilagan, Isabella, 1999.

	Range of amounts applied, kg ha^{-1}			
Nutrient	**None**	**Low**	**Medium**	**High**
N	0	9-40	60-90	120-138
P	0	4-12	17-29	36
K	0	8-23	35	60-100

Analysis of variance using these two levels of N as treatments showed that yield is significantly different between these two clusters (p-value=0.0001) and about 78% of the variation in yield was accounted for by this grouping of N levels (Table 39). Uptake of N, P and K were also significantly different between these N clusters.

Given that K was not a significant factor in the 1999 Ilagan upland rice trial, an analysis of variance was performed with NuMass and NuMaSS+K data combined. NuMass and regional recommendation produced similar yields of 1.2 t ha^{-1}, which was significantly superior to farmer practice and control treatments (Table 40). Similar differences were observed for NPK uptake as well.

Table 39. Grain yield and nutrient uptake by upland rice, 1999, Ilagan, Isabella, Philippines. Data analyzed after separating into two N clusters.

N cluster	Grain Yield	N uptake	P uptake	K uptake
	---------------------------------- kg ha^{-1}	----------------------------------		
9 – 40	633b*	40b	4.8b	40.4b
60 – 138	1160a	86a	9.3a	66.8a

*Values in columns with the same letters are not significantly different at 5% level by LSD.

Table 40. Grain yield and nutrient uptake by upland rice subjected to various nutrient inputs, 1999, Ilagan, Isabella, Philippines.

	Inputs				Grain	Uptake		
Treatments	N	P	K	Lime	yield	N	P	K
	---------- kg ha^{-1} ----------				t/ha	------- kg ha^{-1} -------		
Control	0	0	0	0	0.59c*	37.6c	4.2d	38.2c
Farmer practice	0-134	0-18	0-35	0	0.93b	58.3b	6.8c	53.8b
Regional recommendation	90	9	18	0	1.21a	84.4a	8.8b	61.1ab
NuMaSS and NuMass + K	132	0-36	60-100	0-2000	1.21a	94.7a	10.5a	73.1a

*Values in columns with the same letters are not significantly different at 5% level by LSD.

2. 1999 corn, Ilagan, Isabella - Analyses of variance indicated no significant differences in yield between regional and NuMaSS recommendations but only NuMaSS was superior to farmer practices (Table 41).

Table 41. Grain yield of corn in response to nutrient inputs, 1999 wet season, Ilagan, Isabella, Philippines.

	Inputs				Grain
Treatments	N	P	K	Lime	yield
	----- kg ha^{-1} -----			----- t ha^{-1} -----	
Control	0	0	0	0	1.25c
Farmer Practice	0-274	0-20	0-50	0	3.86b
Regional	134	18	35	0	4.82ab
NuMass	210	0-60	60	0-2	4.95a

*Values in columns with the same letters are not significantly different at 5% level by LSD.

3. 2000 corn, Ilagan, Isabela - Analyses of variance indicated that there were no significant differences in yield among all treatments except the control receiving no inputs (Table 42).

Table 42. Grain yield of corn in response to nutrient inputs, 2000 wet season, Ilagan, Isabella, Philippines.

Treatments	**Nutrients applied** N	P	K	**Grain yield**
	---------- kg ha^{-1}	----------		t ha^{-1}
Control	0	0	0	1.36b
Farmer practice	90-120	12-25	12-23	2.52a
Regional	134	18	35	2.90a
NuMaSS + regional K	225	30-51	35	3.13a
NuMaSS + high K	225	30-51	80	3.10a

*Values in columns with the same letters are not significantly different at 5% level by LSD.

4. 2000 upland rice, Arakan Valley - Analysis of variance of grain yield data showed very large CV and low R^2 with no model significance. This was attributed to the fact that N applied under farmer practice varied widely overlapping with N levels in the regional and NuMaSS treatments. The CV was significantly reduced (20%) and R^2 improved to 91% when the farmer practice N levels were grouped into 16-45, 90 and 113-180 kg ha^{-1} classes and reanalyzed. The results indicated that grain yield under NuMaSS (with regional or high K), regional recommendation and farmer practice with 90 kg N ha^{-1} were similar but significantly higher than the control and farmer practice of low and high N (Table 43). It should be noted that farmer practice did not include any K application and except under low N, no P application as well.

Table 43. Grain yield of upland in response to nutrient inputs, 2000 wet season, Arakan Valley, Philippines.

Treatment	**Nutrients applied** N	P	K	**Grain yield**
	------ kg ha^{-1}	------		t ha^{-1}
Control	0	0	0	0.99c
Farmer practice				
High N	113-180	0	0	1.34c
Medium N	90	0	0	1.77b
Low N	16-45	0-22	0	1.20c
Regional	90	26	25	2.07ab
NuMaSS + regional K	132	0-12	25	2.20a
NuMaSS + high K	132	0-12	67	2.05ab

*Values in columns with the same letters are not significantly different at 5% level by LSD.

Discussion - The on-farm trials collectively indicated that there is a high degree of accuracy in diagnosing constraints of N, P and acidity by NuMaSS. However, the yields achieved for both upland rice and corn were substantially lower than the target yields for which NuMaSS diagnoses and recommendations were made. In general, NuMaSS recommendations resulted in similar yields as the regional recommendation both at the more acid upland site in Ilagan, Isabella and at the less acid site in Arakan Valley for both upland rice and corn crops. Thus,

NuMaSS performed as well as the regional recommendation. But it should be noted that K which is routinely included in the regional recommendation is not currently addressed in NuMaSS. It should be also noted that there were instances where farmer practice yielded the same as regional and NuMaSS recommendations and often with no P and K applied and never any lime applied. A cluster analyses on 1999 upland rice yield in Ilagan indicated that there was a yield response to N but not to P, K or lime. The results overall confirm N but not P, K or acidity as a limitation to yield of upland rice and corn. It cannot be concluded, however that P, K or acidity was not limiting yields since the response to NuMaSS recommendation was observed collectively for N, P and lime. It is likely that the soil P and K supplies were sufficient to support the relatively low yields achieved in the trials. Economic assessment and long term performance of NuMaSS could be evaluated only by accounting for residual effects of P and lime inputs. Although, cooperators were approached about repeating trials on the same plots, only a few farmers repeated their crops in the succeeding year for various reasons including lack of timely rainfall and fallowing the land.
The conclusions that can be drawn are:

- NuMaSS performs as well as the regional recommendation.
- Although NuMaSS target yields were reasonable for the regions, in none of the experiments were such yields produced.
- The treatment combinations did not permit testing whether there were responses to individual nutrient constraints for which NuMaSS diagnoses and recommendations were separately made.

The following recommendations are made for improvement of NuMaSS and the on-farm evaluation of it:

- Achieving target yields may require considerations of other limiting factors such as genotype and time of planting in relation to drought events.
- Currently, P and lime diagnoses and recommendations are based on soil critical levels and are not linked to target yields. Perhaps there is a need to link lime and P diagnoses and recommendations in NuMaSS to target yields.
- Many farmers stiIl use low yielding traditional varieties, however, NuMaSS would still make input recommendations which are suitable and economical only at high yield levels.
- In order to test the success of diagnoses of individual inputs, additional NuMaSS minus-one treatments should be included in on-farm evaluation of NuMaSS. Thus, NuMaSS - N, NuMaSS - P and NuMaSS - lime treatments are recommended. A significant response to NuMaSS treatment compared to NuMaSS – N treatment for example would indicate that the N was indeed deficient.
- It is recommended that two or more replication of treatments are implemented on each farm. This would allow testing of responses on a per farm basis in addition to across all farms.
- Potassium should be included in NuMaSS because it is part of routine regional and national recommendations.
- Land slope should be included as a recommendation criterion in NuMaSS. Recommendations of for large amounts of inputs should not be made for erosion prone lands.

Estimating biologically-fixed N (BNF) inputs in core experiments at the Philippine site (Thomas George, Teodula Corton, Josephina Lasquite, Russell Yost) Estimates of N derived from biological nitrogen fixation (BNF) in response to N, P and lime inputs in the core experiment at Ilagan, Isabella, Philippines were made. Peanut, soybean and mungbean were grown in the experiments in three different seasons. The BNF amount was determined by using the total N uptake of a non-nodulating soybean isoline that was included as one of the treatments. The results are summarized in Tables 44 through 52 and in Figures 7 through 9. The major effect on BNF was from P application; soybean BNF and total N increased substantially while total N and BNF of peanut and mungbean was influenced less so. Nitrogen and lime had no significant effects on total N of all legumes but N decreased the amount of BNF. The total N uptake was strongly related to P uptake in all legumes and appeared to have the same slope when total N and P uptake of all three legumes were plotted together. Accordingly, for every unit uptake of P, there was a corresponding uptake of approximately 9 kg N ha^{-1}. It appears that P fertilzation is the key to realizing increased inputs of BNF in acid uplands such as in Ilagan, Isabella, Philippines. Next step will be to further quantify the BNF benefits so that appropriate predictions of BNF inputs and management options to maximize such benefits could be incorporated into NuMaSS.

Table 44. Effect of N on biologically fixed N (BNF) by peanut, Ilagan, Isabela, Philippines, 1999.

Inputs					
N	**Lime**	**P**	**Total N**	**Soil N***	**BNF***
kg ha^{-1}	t ha^{-1}	-------------------- kg ha^{-1} --------------------			
0	4.18	60	174.5a	44.5	131.0
30	4.18	60	168.9a	59.5	109.4
120	8.37	60	175.6a	104.5	71.0

*The total N uptake by non-nodulating soybean is used as an estimate for N derived from soil by the fixing legume. A 50% recovery was assumed for N fertilizer applied. N from BNF = Total N – N from soil.

Table 45. Effect of P application on biologically fixed N by peanut, Ilagan, Isabela, Philippines, 1999.

Inputs			**Mehlich 1**				
N	**Lime**	**P**	**P[a]**	**Total N**	**Soil N***	**BNF**	**P uptake**
kg ha^{-1}	t ha^{-1}	kg ha^{-1}	mg kg^{-1}	-------------------- kg ha^{-1} --------------------			
30	4.18	0	2.89c	161.9a	59.5	102.3	10.5b
30	4.18	30	6.48c	170.4a	59.5	110.8	14.6ba
30	4.18	60	14.49b	168.9a	59.5	109.4	17.0a
30	4.18	120	22.33a	177.8a	59.5	118.3	18.0a

[a] After harvest.

*The total N uptake by non-nodulating soybean is used as an estimate for N derived from soil by the fixing legume. A 50% recovery was assumed for N fertilizer applied. N from BNF = Total N – N from soil.

Table 46. Effect of lime application on biologically fixed N by peanut, Ilagan, Isabela, Philippines, 1999.

Inputs					
N	Lime	P	Total N	Soil N*	BNF*
kg ha^{-1}	t ha^{-1}	-----------------	kg ha^{-1}	-----------------	
0	4.18	120	187.0a	44.5	142.5
0	8.37	120	185.9a	44.5	141.3

*The total N uptake by non-nodulating soybean is used as an estimate for N derived from soil by the fixing legume. A 50% recovery was assumed for N fertilizer applied. N from BNF = Total N – N from soil.

Table 47. Effect of N on biologically fixed N (BNF) by soybean, Ilagan, Isabela, Philippines, 2000.

Inputs					
N	Lime	P	Total N	Soil N*	BNF*
kg ha^{-1}	t ha^{-1}	-----------------	kg ha^{-1}	-----------------	
0	4.18r*	50f*+60r	103.5a	57.9	45.6
30	4.18r	50f+60r	112.6a	62.9	39.7
135	8.37r	50f+60r	126.0a	125.4	0.7

f=freshly applied, r=residual from 1999 Peanut application

*The total N uptake by non-nodulating soybean is used as an estimate for N derived from soil by the fixing legume. A 50% recovery was assumed for N fertilizer applied. N from BNF = Total N – N from soil.

Table 48. Effect of P application on biologically fixed N by soybean, Ilagan, Isabela, Philippines, 2000.

Inputs			Mehlich 1 P[a]					
N	Lime	P[+]	Before	After	Total N	Soil N	BNF*	P uptake
kg ha^{-1}	t ha^{-1}	kg ha^{-1}	--- mg kg^{-1} ---		-------------	kg ha^{-1}	-------------	
30	4.18r	0	3.99	1.06 b	45.8c	45.8	0	2.3c
30	4.18r	25f+30r	4.65	4.28 b	83.0b	57.9	10.1	7.8b
30	4.18r	50f+60r	8.20	6.25 b	112.6ba	57.9	39.7	11.4a
30	4.18r	100f+120r	12.40	13.02 a	130.9a	57.9	58.0	13.6a

[+]r=residual, f=freshly applied

[a] samples taken before and after harvest

*The total N uptake by non-nodulating soybean is used as an estimate for N derived from soil by the fixing legume. A 50% recovery was assumed for N fertilizer applied. N from BNF = Total N – N from soil.

Table 49. Effect of lime application on biologically fixed N by soybean, Ilagan, Isabela, Philippines, 1999.

Inputs					
N	**Lime**	**P**	**Total N**	**Soil N***	**BNF***
kg ha^{-1}	t ha^{-1}	--------------- kg ha^{-1} --------------			
0	4.18r[1]	100f+120r	133.2a	57.9	75.3
0	8.37r	100f+120r	128.4a	57.9	70.6

* The total N uptake by non-nodulating soybean is used as an estimate for N derived from soil by the fixing legume. A 50% recovery was assumed for N fertilizer applied. N from BNF = Total N – N from soil.

[1]r=residual from 1999 Peanut application

Table 50. Effect of N on biologically fixed N (BNF) by mungbean, Ilagan, Isabela, Philippines, 2000.

Inputs					
N	**Lime**	**P**	**Total N**	**Soil N***	**BNF***
kg ha^{-1}	t ha^{-1}	-------------------- kg ha^{-1} --------------------			
0	0.5f[1] + 4.18r2[1]	60f+50r1[1]+60r2	46.9a	59	0
30	0.5f + 4.18r2	60f+50r1+60r2	60.0a	59	0
210	0.5f + 8.37r2	90f+50r1+60r2	52.9a	>52.9	0

* The total N uptake by non-nodulating soybean is used as an estimate for N derived from soil by the fixing legume. A 50% recovery was assumed for N fertilizer applied. N from BNF = Total N – N from soil.

[1]f=freshly applied, r1=residual from 2000 soybean, r2=residual from 1999 peanut

Table 51. Effect of P application on biologically fixed N by mungbean, Ilagan, Isabela, Philippines, 2000.

Inputs			Mehlich 1-P		Total			P
N	**Lime**	**P**	**Before**	**After**	**N**	**Soil N***	**BNF***	**uptake**
kg ha^{-1}	t ha^{-1}	kg ha^{-1}	mg kg^{-1}		------------- kg ha^{-1} -------------			
30	0.5f+ 4.18r2	0	1.06 b	2.30	19.5b	>19.5	0	1.5b
30	0.5f +4.18r2	30f+25r1+30r2	4.28 b	5.80	49.3a	>49.3	0	5.2a
30	0.5f +4.18r2	60f+50r1+60r2	6.25 b	9.17	60.0a	59	1	6.8a
30	0.5f +4.18r2	90f+100r1+120r2	13.02 a	16.11	55.4a	>55.4	0	6.2a

* The total N uptake by non-nodulating soybean is used as an estimate for N derived from soil by the fixing legume. A 50% recovery was assumed for N fertilizer applied. N from BNF = Total N – N from soil.

[1]f=freshly applied, r1=residual from 2000 soybean, r2=residual from 1999 peanut

Table 52. Effect of lime application on biologically fixed N by mungbean, Ilagan, Isabela, Philippines, 1999

Inputs					
N	Lime	P	Total N	Soil N*	BNF*
kg ha^{-1}	t ha^{-1}		kg ha^{-1}		
0	0.5f +4.18r2	100r1+120r2	47.5a	47.5	0
0	4.0f +8.37r2	100r1+120r2	55.9a	52.9	0

* The total N uptake by non-nodulating soybean is used as an estimate for N derived from soil by the fixing legume. A 50% recovery was assumed for N fertilizer applied. N from BNF = Total N – N from soil.

[1]f=freshly applied, r1=residual from 2000 soybean, r2=residual from 1999 peanut

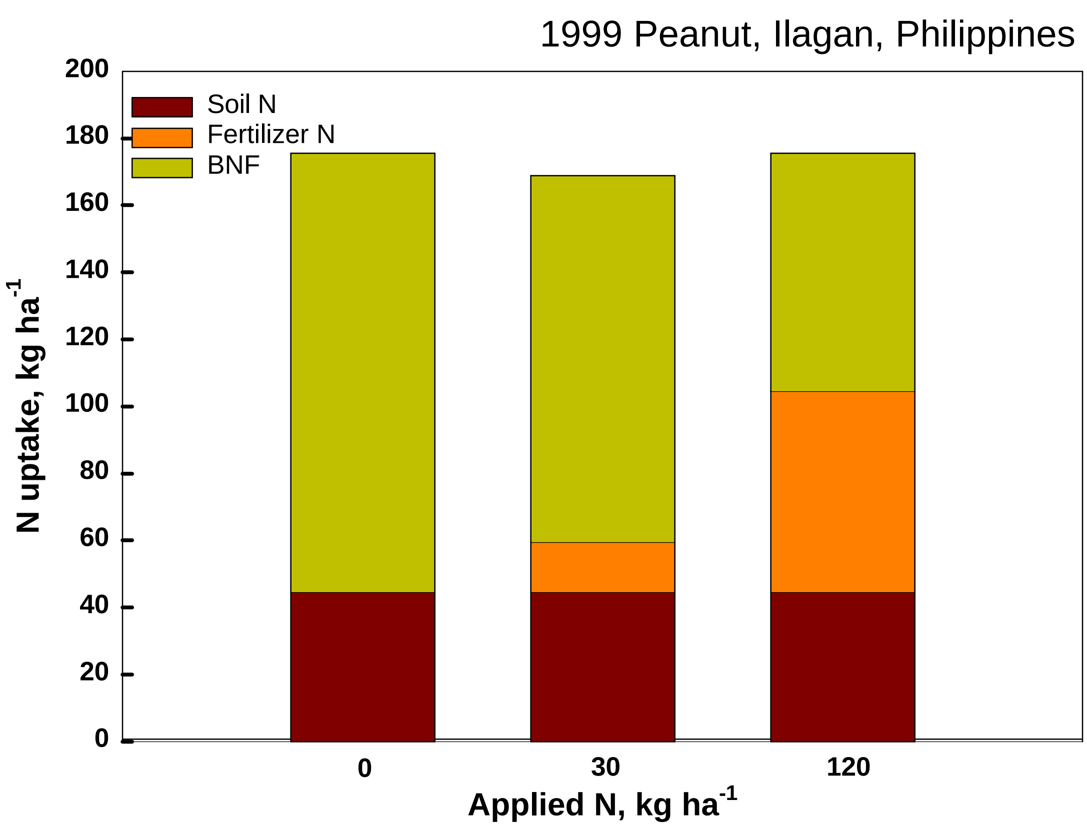

Figure 7. Effect of applied N on soil N , BNF and total N uptake by peanut, 1999, Ilagan, Philippines.

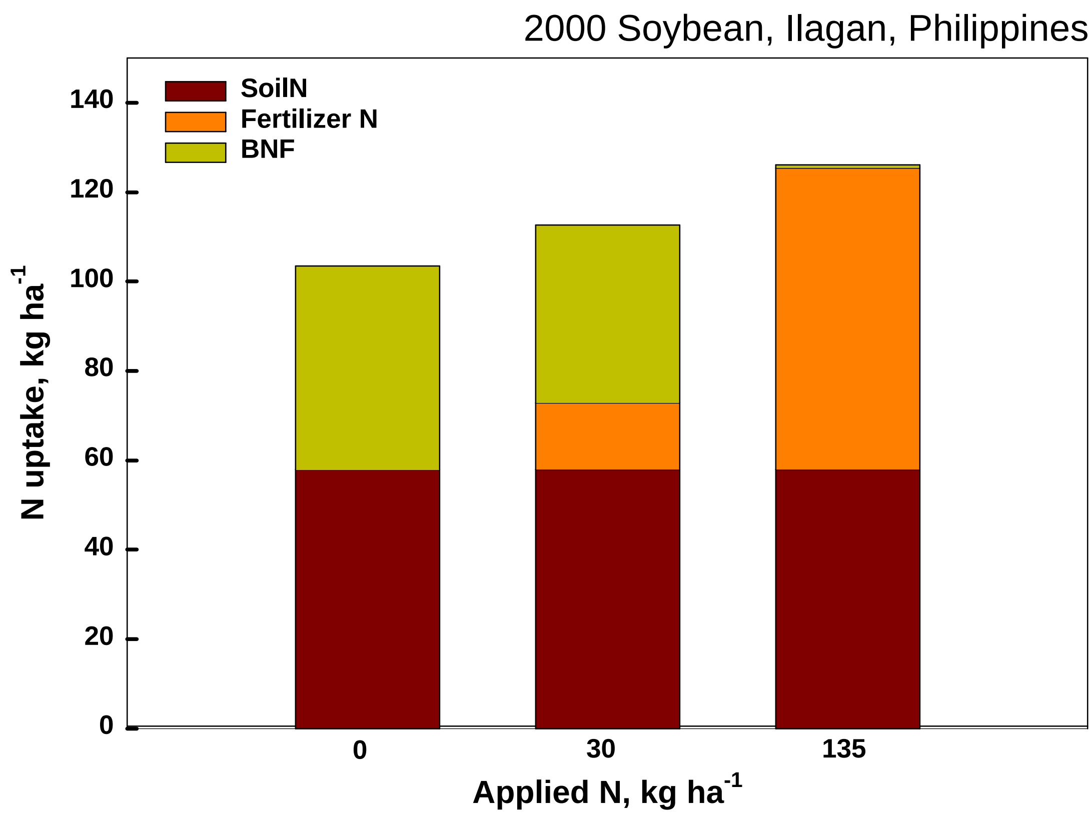

Figure 8. Effect on applied N on soil N, BNF and total N uptake by soybean, 2000, Ilagan, Philippines

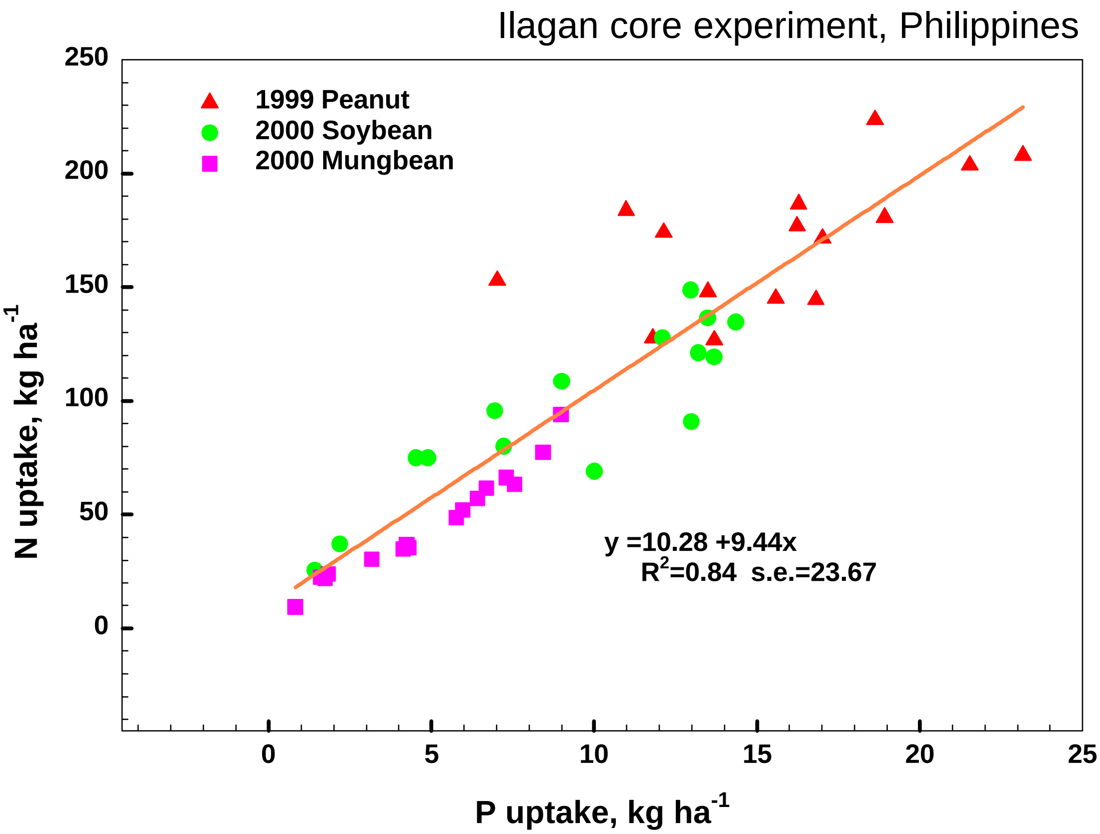

Figure 9. P uptake vs. N uptake, 1999 peanut, 2000 soybean and 2000 mungbean, Ilagan core experiment, Philippines

Investigation of Mn toxicity problem in the Core Experiment Site in Brangay San Antonio, Isabela, Philippines

(Jocelyn Bajita, Josefina Lasquite, Russell Yost with collaboration of Quirino Asuncion)
This investigation had the following objectives: 1. collect available information on the extent of Mn toxicity problem in the acid uplands of the Philippines and the methods used to diagnose the problem; 2. observe the extent to which Mn toxicity is expressed in the growing crop and gain insight on how Mn toxicity can complicate responses to lime, P and green manure application in an acid upland soil; and 3. conduct field, greenhouse and lab experiments to assess the realative contribution of various management practices (variety, liming, green manure application) on manganese toxicity in an acid upland soil.
Literature search at the IRRI library revealed no past nor recent investigations on Mn toxicity in the acid uplands. There were occasional papers and thesis written on Mn availability and excess in paddy rice fields but not in the acid uplands. To date there is no existing estimate of the potential risk of acid soils for Mn toxicity from the Philippine Bureau of Soils and Water Management or from other institutions like University of the Philippines Los Banos that conducts research on acid soils. Dr. Rodrigo Badayos, a professor and geologist of the

university and his staff constructed a map of ultrabasic rock derived soils that may be useful in locating high Mn soils in the Philippines.

Local farmers in San Antonio are well aware that many soils in their *barangay* and nearby areas have manganese nodules they call "*bagiing*". These "*bagiings*" they reported, can cause problems in their crop when episodes of heavy rains come and their crop is still young. The corn and rice crop in the area appears to be normal and do not show symptoms of Mn toxicity. The travel coincided with the summer crop June-September 2000 when majority of the farmers are growing corn. Some flat areas, small valleys and footslopes are planted to rice, while some more steep areas are planted to vegetables. The summer months, according to the experiment station personnel used to have episodes of heavy rains starting in August. There was less rain in 2000, about 7 mm maximum and about two short rainshowers once in two weeks during the conduct of the field experiment. Heavier rains were experienced only when typhoons and tropical depressions develop.

Officials of Ilagan Experiment Station and PhilRice were contacted initially to discuss the pre-planned experiments and get their suggestions, comments and ideas regarding the problem addressed by the planned study. They expressed their support in terms of the use of experiment station facilities. The field experiment was established at Centro San Antonio, Ilagan Isabela, Philippines on June 28, 2000, after 4 weeks of preparation of the field site and materials. Seeds of soybean UPL Sy2 and UPL Sy6, rated as acid susceptible and acid tolerant, respectively, were obtained from IES and Institute of Plant Breeding. The experimental site identified by Mr. Asuncion is owned by the *barangay* school and is located about 400 meters northeast of the Core Experiment of the SM-CRSP. The pot experiment was established on June 28, 2000 at the screenhouse facility of the IES. The laboratory experiment was conducted at the Soils Laboratory of PhilRice. The establishment of both field and pot experiment was facilitated by Ms. Lasquite and Mr. Asuncion with the participation of other IES staff and local field workers in San Antonio. The same persons helped during sampling of soil and plants from the experiments. Soils and plant samples were brought to PhilRice immediately after sampling for processing and analysis, and for measurements such as leaf area and biomass weight. Plant observations on Mn toxicity symptoms were made on-site and digital pictures were taken to document the symptoms.

The soil used in the experiments is a *fine, isohyperthermic Typic Kandiudalfs*, very acid (pH 4.5), high in Al (47% in the exchange complex) and low in exchangeable bases (2.5 cmol kg-1). I tested the effects of lime, green manure and variety on toxicity responses of soybean to Mn toxicity. Water availability treatments were also tested in the greenhouse experiment.

The field-grown soybean showed severe of Mn toxicity characterized by the following symptoms:

appearance of black speckles, black spots and lesions in older leaves, irregular yellowing of interveinal tissues of young and old leaves, and crinkling of young leaves.

These symptoms started to develop during the primary leaf stage and were fully expressed at two weeks after planting. A rating scheme was devised: 1 for plants having no symptom and 5 for plants showing all the symptoms described above. Symptoms were most severe in plots without lime. Soybean variety *UPL SY2* appeared to be more tolerant of soil acidity compared to *UPL SY6* as shown by less severe symptoms and higher leaf concentrations of Ca. Plants with severe leaf symptoms were also severely stunted. The plants somewhat recovered, exhibiting less symptom during the next two weeks of growth. Six weeks after planting, the symptoms became more severely expressed particularly in unlimed plots where no green manure was added. Folding of the leaves of *UPL SY2* was observed at this stage. Liming and green manure application appeared to help the plants grow bigger and faster as shown by higher biomass growth rates, leaf expansion rates, and specific leaf weights (Table 53). This effect was very pronounced both in limed and unlimed plots. Liming reduced leaf Mn concentration from about 1,300 mg kg^{-1} to 460 mg kg^{-1}. Without lime application, green manure application significantly reduced leaf Mn. Seed yield was significantly increased by liming and green manure application, and was significantly less in UPL SY6 across liming and green manure treatments (Table 53).

The soybean plants in the greenhouse did not show any serious symptoms of Mn toxicity except for some treatments where the old leaves showed few black spots. We think that this happened for two reasons: the soil was incubated under field capacity for two weeks before planting soybean and that greenhouse conditions (temperature and water?) favored a faster growth rate for the plants during the first two weeks. Greenhouse plants tended to be bigger and healthier during the first two weeks, as compared with field plants. Field and greenhouse plants also differed in stature, the field plants were shorter but with thicker leaves and stems while the greenhouse plants were taller, with thinner leaves and stems. Eventually, greenhouse plants exhibited viny growth which according to Ms Rosie, soybean expert of IES, normally happens when soybean is grown under partly shaded condition and is constantly supplied with water. Liming and green manure application significantly increased leaf and biomass growth rates and leaf area at 6 weeks after planting (Table 54). Applying green manure increased leaf Mn from 283 mg kg^{-1} to 499 mg kg^{-1} without lime application. With lime, leaf Mn averaged at 227 mg kg^{-1} and did not differ significantly with lime or green manure application (Table 54).

Table 53. Toxicity ratings, biomass production and leaf area of two field-grown soybean varieties grown in acid soil of the Barangay San Antonio, Ilagan, Isabela, Philippines. June-October 2000.

						Biomass					
	Green		Toxicity Ratings[a]			Wk 4		Wk 6		Leaf Area	
Lime	Manure	Variety	Wk 2	Wk 4	Wk 6	Leaf	Plant	Leaf	Plant	Wk 4	Wk 6
$t\ ha^{-1}$						$g\ m^{-2}$				$cm^2\ m^{-2}$	
0	0	UPL Sy2	3.50	2.75	3.38	4.35	7.04	7.34	13.15	199.3	1598.5
0	0	UPL Sy6	4.00	3.38	4.00	4.40	7.33	6.79	12.40	296.2	1925.5
0	7	UPL Sy2	2.13	2.25	2.13	5.01	8.64	13.10	25.28	277.1	3113.6
0	7	UPL Sy6	3.03	2.75	3.13	4.06	7.17	9.24	16.28	160.9	2060.3
5	0	UPL Sy2	1.13	1.00	1.13	5.37	9.44	14.26	27.06	585.0	3746.2
5	0	UPL Sy6	2.50	2.63	2.63	6.55	11.38	14.85	27.86	285.9	3126.0
5	7	UPL Sy2	1.00	1.00	1.00	6.01	10.29	21.33	38.71	572.5	2810.6
5	7	UPL Sy6	2.63	2.38	2.63	5.16	9.02	11.12	24.86	978.5	2633.7
$LSD_{0.05}$			0.34	0.36	0.34	0.58	1.00	3.98	5.34	359.3	622.3

[a] 1(healthy)-5(severe symptoms)

Table 54. Leaf Mn, growth rates and yield of two field-grown soybean varieties grown to acid soil in Barangay San Antonio, Ilagan, Isabela, Philippines. June-October 2000.

	Green		Growth rate[a]		Leaf Mn		Seed
Lime	Manure	Variety	Leaf	Plant	Wk 4	Wk 6	yield
$t\ ha^{-1}$			$mg\ d^{-1}$		$mg\ kg^{-1}$		$kg\ ha^{-1}$
0	0	UPL Sy2	38.04	68.3	2125	1577	690
0	0	UPL Sy6	30.67	68.93	1733	1461	569
0	7	UPL Sy2	82.24	155.42	1506	1090	1499
0	7	UPL Sy6	56.49	97.60	1496	988	1148
5	0	UPL Sy2	80.09	153.46	445	367	1848
5	0	UPL Sy6	68.68	127.98	596	470	1663
5	7	UPL Sy2	114.73	205.96	571	483	1945
5	7	UPL Sy6	80.76	146.58	511	519	1660
$LSD_{0.05}$			11.43	20.18	218	321	181.41

[a] (within 6-wk period).

Table 55. Biomass production, growth rates, leaf area and leaf Mn of two greenhouse-grown soybean varieties grown to acid soil in Barangay San Antonio, Ilagan, Isabela, Philippines. June-October 2000.

				Biomass								
				Wk 4		**Wk 6**		**Growth Rate**[a]		**Leaf Area**		**Leaf**
Lime	**Green Manure**	**Variety**	**Water**	**Leaf**	**Plant**	**Leaf**	**Plant**	**Leaf**	**Plant**	**Wk 4**	**Wk 6**	**Mn**
t ha^{-1}				g plant^{-1}				mg d^{-1}		cm^2 plant^{-1}		mg kg^{-1}
0	0	UPL Sy2	Field Cap	0.400	0.802	1.296	2.824	41.1	91.1	208.2	572.7	273
0	0	UPL Sy2	Wet	0.442	0.849	1.776	3.731	58.5	124.5	280.3	712.2	
0	0	UPL Sy6	Field Cap	0.412	0.822	1.214	2.887	39.9	74.9	289.9	426.8	293
0	0	UPL Sy6	Wet	0.302	0.742	1.415	3.261	45.7	107.3	220.8	710.4	
0	7	UPL Sy2	Field Cap	0.521	1.070	2.481	5.017	82.5	167.5	390.3	985.1	586
0	7	UPL Sy2	Wet	0.453	0.948	2.454	5.241	83.4	179.4	276.4	1028.0	
0	7	UPL Sy6	Field Cap	0.286	0.680	1.928	4.488	65.5	15.0	200.1	774.9	412
0	7	UPL Sy6	Wet	0.285	0.609	2.018	4.503	67.8	153.1	198.7	1060.2	
5	0	UPL Sy2	Field Cap	0.352	0.729	1.189	2.374	36.8	74.4	226.2	397.1	209
5	0	UPL Sy2	Wet	0.399	0.807	1.287	2.523	41.6	81.6	256.5	461.5	
5	0	UPL Sy6	Field Cap	0.186	0.425	0.945	1.191	29.0	69.2	130.9	402.4	227
5	0	UPL Sy6	Wet	0.299	0.772	0.918	2.148	28.2	53.5	213.0	437.8	
5	7	UPL Sy2	Field Cap	0.471	0.918	1.760	3.715	58.4	123.7	283.3	671.5	225
5	7	UPL Sy2	Wet	0.412	0.845	1.001	2.210	29.7	68.5	276.1	437.9	
5	7	UPL Sy6	Field Cap	0.352	0.773	1.215	2.844	40.1	95.2	254.9	491.8	247
5	7	UPL Sy6	Wet	0.273	0.649	1.443	3.281	47.3	108.7	199.9	509	
$LSD_{0.05}$				0.057	0.103	0.264	0.619	8.8	20.6	34.3	106.3	90

Field Cap – field capacity

[a] (within 6-wk period)

Core experiment top test individual module predictions of nutrient requirements and to develop supporting data to estimate interactions among N, P and lime rates

(Teodula Corton, Miguel Aragon, Russell Yost, Thomas George, Josefina Lasquite with collaboration from Santiago R. Obien, Segunda Santiago, Danilo B. Tumamao, Quirino Asuncion and Thomas George) objectives of this investigation are to: 1) conduct factorial experiments that will support Level 0 (comparing yield predictions) testing of the ADSS, PDSS and NDSS or equivalent N recommendations methodology for alternative upland cropping systems; 2) collect data for Level 1 (both yield prediction and parameter testing) for a selected cropping system for PDSS, ADSS and NDSS; and 3) develop management alternatives (crop and amendment combinations) that might be used in subsequent outreach testing locations throughout the non-irrigated rice-based systems in the Philippines.

Field experiments were conducted for cereal (rice and corn) and legume crops (peanut, soybean and mungbean) during the 1998-2000 cropping seasons in Ilagan, Isabela, Philippines. Crop responses to lime, N and P are summarized in Tables 56-67 (rice, corn) and Tables 69-83 (peanut, soybean, mungbean) . Soil analysis after harvest of the 2000 corn crop showed a significant increase in soil pH and a decrease in exchangeable aluminum where lime was applied (Table 68). Phosphorus uptake and N uptake were strongly related in both upland rice and corn (Fig. 14).

The 1998 rice crop did not respond to lime, N and P application. Grain yield across treatments was at least 2 t ha^{-1}, which is far below the target of 3.5 t ha^{-1}. While upland rice in 1998 did not respond to any of the N, P or lime inputs, it did respond to P in 1999; grain yield, N and P uptake significantly increased with P application. The relationship between Mehlich 1 P at crop harvest and grain yield produced a scatter plot in 1998 (Fig. 10) while in 1999 (Fig. 12) the data fit a linear-response-plateau model. The critical Mehlich 1 P level of 6.2 mg kg^{-1} was identified in 1999.

There was no yield response to N application in the 1999 corn crop while a significant response was obtained in 2000. Significant increase in grain yield was obtained at the highest lime rate in both years. There was a response to P in both years, but only at the highest P rate of 90 kg P ha^{-1} which received also the highest rate of N of 300 kg ha^{-1}. Analysis of covariance indicated that there were no interaction between P treatment levels and N uptake, and therefore, the differences in the N rate between the P levels was considered not to significantly influence the yield response to the high P rate. The relation between Mehlich 1 P at harvest and corn yield shown in Fig 11 and 13 indicate a critical P level of 17.5 mg kg^{-1} in 1999 and 9.3 mg kg^{-1} in 2000.

The peanut crop did not respond to the small initial N application nor to lime application. However, further analysis showed that lime contributed to yield when green manure was also applied (Table 73). Phosphorus response was significant at 30 kg ha^{-1} rate, with no further response with additional P applied. Similarly, soybean did not respond to N and lime application. Lime appeared to increase grain yield, N and P uptake only when green manure is present (Table 78). Grain yield, N and P uptake increased significantly with the application of P up to 50 kg ha^{-1} (with P residual from previous crops). Mungbean responded to 30 kg N ha^{-1} application. Lime response was not observed, even when applied with green manure (Table 83). A strong P response was obtained up to 60 kg ha^{-1} P plus residuals. Critical P levels identified for the legumes appeared to be very low at about 5.8 mg kg^{-1} for peanut and 4.8 mg kg^{-1} for soybean (Fig 15 and 16).

Table 56. Nitrogen response, 1998 Rice, Ilagan

Inputs			N uptake	P uptake	Grain yield
N	Lime	P			
kg ha^{-1}	t ha^{-1}		kg ha^{-1}		
0	6	30	77.3a	10.1a	1917a
40	6	30	79.5a	10.1a	1952a
80	6	30	81.4a	8.3a	2004a
120	6	30	96.6a	9.9a	1711a

Table 57. P response, 1998 Rice, Ilagan

Inputs						
N	Lime	P	Mehlich 1-P	N uptake	P uptake	Grain Yield
kg ha^{-1}	t ha^{-1}	kg ha^{-1}	ug g^{-1}	---------- kg ha^{-1} ----------		
80	6	0	10.6a	84.2a	7.6a	1636a
80	6	15	19.5a	81.4a	7.2a	1692a
80	6	30	14.4a	77.6a	8.3a	2004a
120*	6	60	20.5a	98.0a	9.4a	1772a

*The higher N rate treatment included in the analyses since the ANOCOVA analysis for interaction between N uptake (as a proxy to N applied) and P treatment levels was not significant.

Table 58. Lime response, 1998 Rice, Ilagan.

Inputs					
N	Lime	P	N uptake	P uptake	Grain Yield
kg ha^{-1}	t ha^{-1}	kg ha^{-1}	---------- kg ha^{-1} ----------		
80	0	30	69.4a	7.2a	1680a
80	3	30	81.4a	8.3a	1643a
80	6	30	70.8a	7.4a	2004a

Table 59. N response, 1999 Corn, Ilagan

Inputs					
N	Lime	P	N uptake	P uptake	Grain Yield
kg ha^{-1}	t ha^{-1}	kg ha^{-1}	---------- kg ha^{-1} ----------		
0	6r*	45	65.9b	2.9a	4650a
100	6r	45	76.9ab	3.4a	5084a
200	6r	45	70. 7ab	3.4a	4623a
300	6r	45	82.9a	3.2a	5377a

*r=residual from 1998 Rice

Table 60. P response, 1999 Corn, Ilagan

Inputs			Mehlich 1 P			
N	Lime	P	after harvest	N uptake	P uptake	Grain yield
kg ha^{-1}	t ha^{-1}	kg ha^{-1}	mg kg^{-1}	---------- kg ha^{-1} ----------		
200	6r[1]	0	2.8c	62.1b	2.5b	3971b
200	6r	22.5	3.9 cb	78.9ab	3.0b	4791b
200	6r	45	8.4b	70.7b	3.4b	4622b
300*	6r	90	17.3a	98.6a	4.8a	6208a

[1]r=residual from 1998 Rice

* The higher N rate treatment included in the analyses since the ANOCOVA analysis for interaction between N uptake (as a proxy to N applied) and P treatment levels was not significant

Table 61. Lime response, 1999 Corn, Ilagan

Inputs					
N	**Lime**	**P**	**N uptake**	**P uptake**	**Grain yield**
kg ha^{-1}	t ha^{-1}	--------------- kg ha^{-1} ---------------			
200	0	30	66.3b	2.6b	4275b
200	3r*	30	87.3a	3.5a	4623b
200	6r	30	70.7b	3.4a	5688a

*r=residual from 1998 Rice

Table 62. N response, 1999 Rice, Ilagan.

Inputs					
N	**Lime**	**P**	**N uptake**	**P uptake**	**Grain Yield**
kg ha^{-1}	t ha^{-1}	kg ha^{-1}	---------- kg ha^{-1} -----------		
0	6r*	45	32.0c	6.1b	1011c
50	6r	45	46.6b	8.0ab	1511bc
100	6r	45	68.6a	8.3ab	1691ba
150	6r	45	77.9a	10.3a	2079a

*r=residual from 1998 Rice

Table 63. P response, 1999 Rice, Ilagan.

Inputs			Mehlich 1 P			
N	Lime	P	after harvest	N uptake	P uptake	Grain Yield
kg ha^{-1}	t ha^{-1}	kg ha^{-1}	mg kg^{-1}		kg ha^{-1}	
200	6r[1]	0	2.3c	50.7b	4.8b	1136b
200	6r	22.5	5.7cb	63.2b	8.4a	1567ba
200	6r	45	9.2ba	68.6a	8.3a	1691a
300*	6r	90	12.4a	82.4a	10.5a	2017a

[1]r=residual from 1998 Rice

* The higher N rate treatment included in the analyses since the ANOCOVA analysis for interaction between N uptake (as a proxy to N applied) and P treatment levels was not significant.

Table 64. Lime response, 1999 Rice, Ilagan.

Inputs					
N	Lime	P	N uptake	P uptake	Grain Yield
kg ha^{-1}	t ha^{-1}	--------------- kg ha^{-1} ---------------			
200	0	30	71.4a	7.6a	1730a
200	3r*	30	60.9a	7.8a	1441a
200	6r	30	68.6a	8.3a	1691a

*r=residual from 1998 Rice

Table 65. N response, 2000 Corn, Ilagan.

Inputs					
N	Lime	P	N uptake	P uptake	Grain Yield
kg ha^{-1}	t ha^{-1}			kg ha^{-1}	
0	6r*	60	82.7c	14.5a	5283c
100	6r	60	111.8b	15.7a	5802b
200	6r	60	132.8a	19.2a	5818b
300	6r	60	128.78ab	18.8a	6161a

*r=residual from 1998 Rice

Table 66. P response, 2000 Corn, Ilagan

Inputs			Mehlich 1 P			
N	**Lime**	**P**	**after harvest**	**N uptake**	**P uptake**	**Grain Yield**
kg ha^{-1}	t ha^{-1}	kg ha^{-1}	ug g^{-1}		kg ha^{-1}	
200	6r[1]	0	2.2b	45.6c	4.7c	2044d
200	6r	30	10.4b	102.2b	12.6b	4822c
200	6r	60	13.2b	132.8a	19.2a	5818b
300*	6r	120	51.0a	139.8a	21.2a	6475a

[1]r=residual from 1998 Rice

* The higher N rate treatment included in the analyses since the ANOCOVA analysis for interaction between N uptake (as a proxy to N applied) and P treatment levels was not significant.

Table 67. Lime response, 2000 Corn, Ilagan.

Inputs					
N	**Lime**	**P**	**N uptake**	**P uptake**	**Grain Yield**
kg ha^{-1}	t ha^{-1}		---------------- kg ha^{-1} ----------------		
200	0	60	93.1b	12.2b	4258b
200	3r*	60	95.4b	13.5b	4554b
200	6r	60	132.8a	19.2a	5818a

*r=residual from 1998 Rice

Table 68. Soil analysis (0-15 depth) after harvest of the corn crop (Hybrid Cargill 818) planted in an acid upland site in Barangay San Antoni, Ilagan, Isabela, Philippines. 2000 Wet Season.

Lime*	GM	N	P	K	pH	Mehlich 1 P	OC	Exch. Acidity	Exch. Aluminum
	t ha^{-1}		kg ha^{-1}		1:1H2O	mg kg^{-1}	%	$cmol_c$ kg^{-1}	
L0	-	0	0	60	4.42	2.62	1.36	2.47	2.18
L0	-	200	60	60	4.28	14.46	1.52	1.84	1.66
L2	-	0	60	60	6.42	19.12	1.32	0.98	0.92
L2	-	200	0	60	6.07	2.49	1.32	0.02	0.00
L2	-	100	60	60	6.23	23.19	1.26	0.03	0.00
L2	-	200	60	60	6.07	13.20	1.36	0.02	0.00
L2	-	300	60	60	5.81	13.71	1.43	0.02	0.00
L2	-	200	30	60	6.33	10.37	1.21	0.02	0.00
L2	-	300	120	60	5.82	50.96	1.18	0.02	0.00
L2	-	100	30	60	5.92	6.57	1.40	0.02	0.01
L1	-	200	60	60	5.15	9.32	1.29	0.10	0.04
L2	-	200	60	60	5.05	12.28	1.25	0.05	0.02
L0	5	200	60	60	4.39	15.76	1.53	1.80	1.61
L1	5	200	60	60	5.04	10.94	1.45	0.19	0.12

*No lime applied, lime level is based on lime applied on the previous crop.

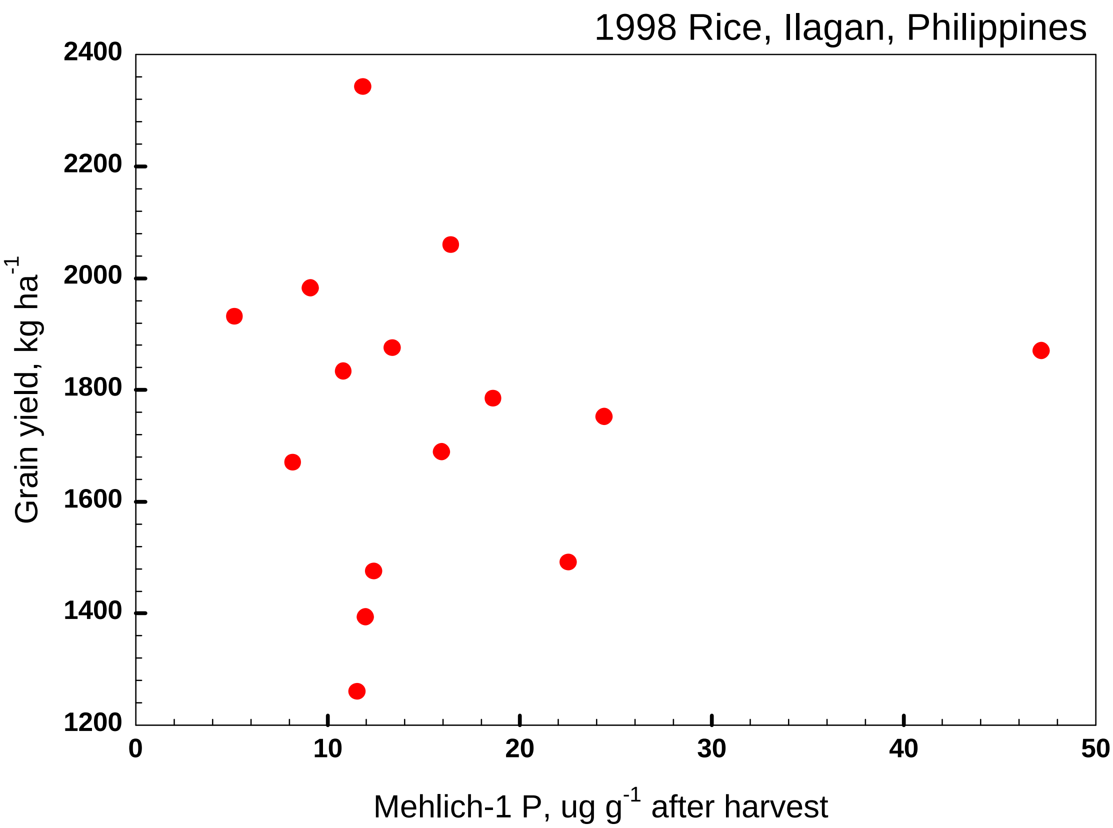

Figure 10. Mehlich 1 P vs. grain yield, 1998 Rice, Ilagan, Philippines.

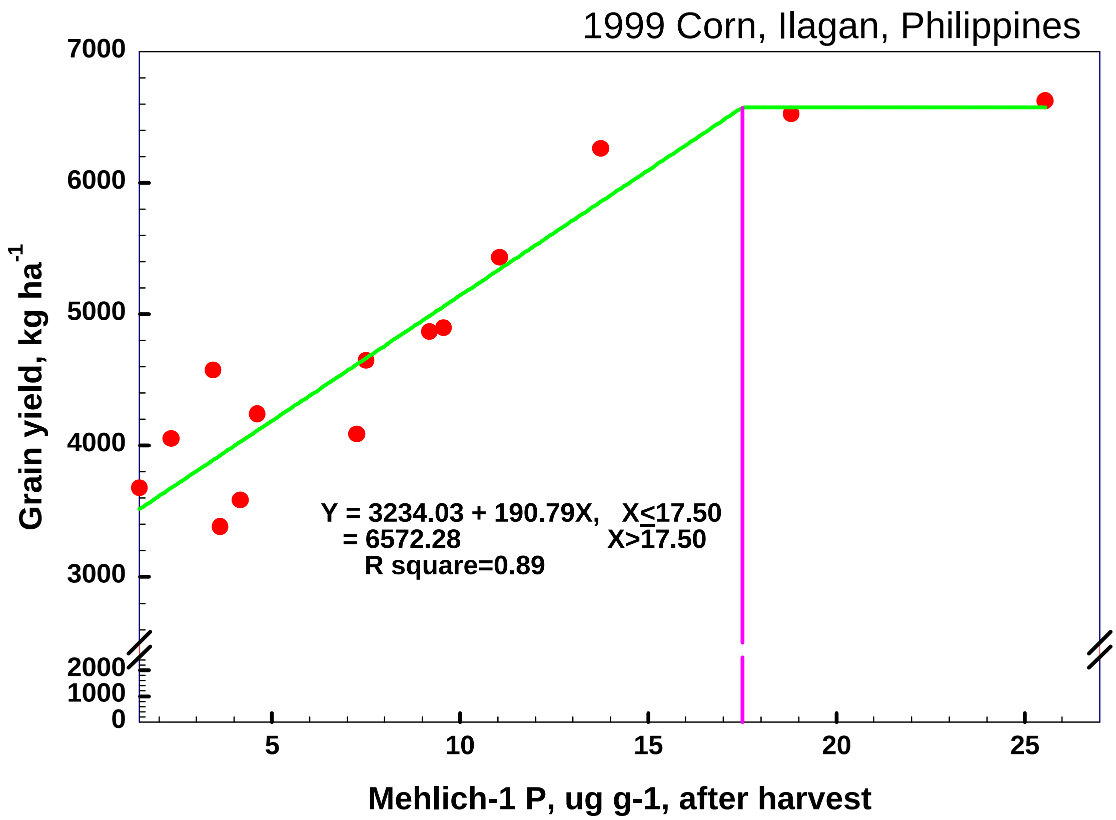

Figure 11. Mehlich 1 P vs. grain yield, 1999 corn, Ilagan, Philippines.

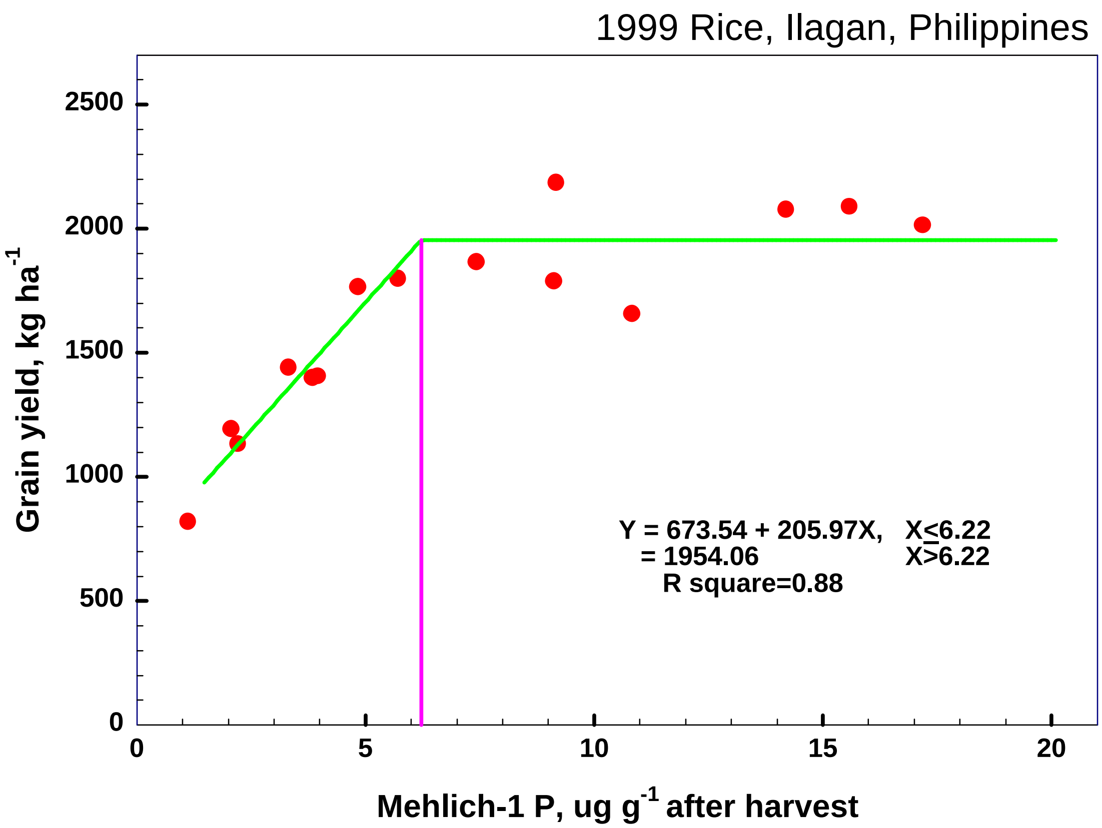

Figure 12. Mehlich 1 P vs rice yield, 1999, Ilagan, Philippines.

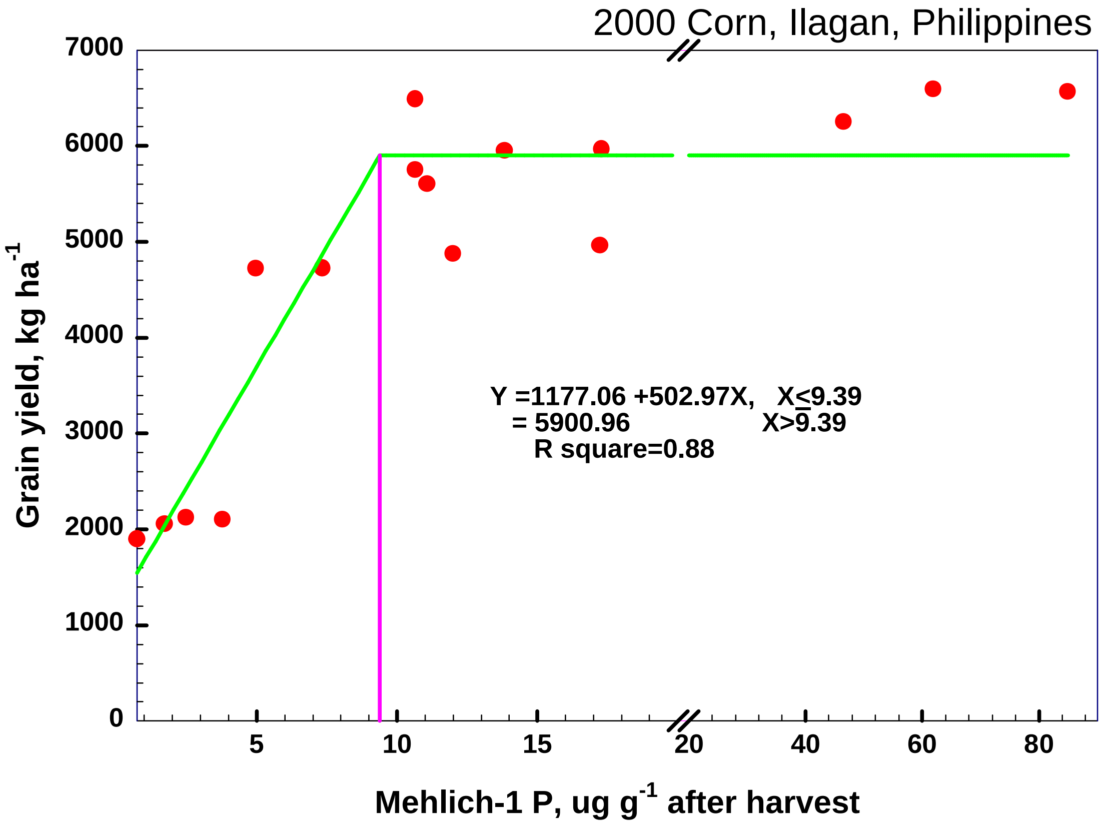

Figure 13. Mehlich 1 P vs. corn grain yields, 2000, Ilagan, Philippines.

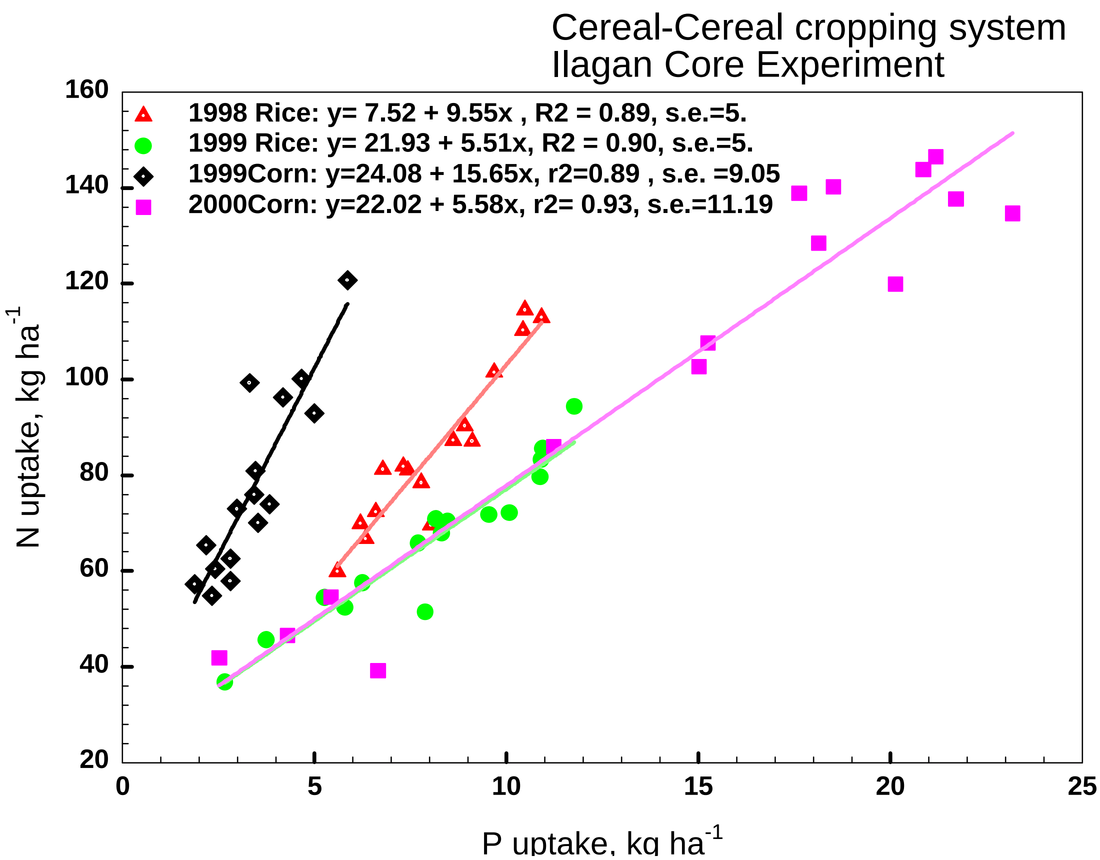

Figure 14. P uptake vs N uptake for 1998 Rice - 2000 corn crops, Ilagan, Philippines.

Table 69. N response, 1999 Peanut, Ilagan.

Inputs					
N	**Lime**	**P**	**N uptake**	**P uptake**	**Grain yield**
kg ha^{-1}	t ha^{-1}			kg ha^{-1}	
0	4.18	60	174.6a	16.8a	1793a
30	4.18	60	168.9a	17.0a	1756a
120	8.37	60	175.6a	16.2a	1797a

Table 70. P response, 1999 Peanut, Ilagan.

Inputs			Mehlich 1 P			
N	**Lime**	**P**	**after harvest**	**N uptake**	**P uptake**	**Grain Yield**
kg ha^{-1}	t ha^{-1}	kg ha^{-1}	ug g^{-1}	----------	kg ha^{-1}	----------
30	4.2	0	2.9c	161.9a	10.5b	589b
30	4.2	30	6.5c	170.4a	14.6ba	1797a
30	4.2	60	14.5b	168.9a	17.0a	1756a
30	4.2	120	22.3a	177.8a	18.0a	1822a

Table 71. Lime response, 1999 Peanut, Ilagan.

Inputs					
N	**Lime**	**P**	**N uptake**	**P uptake**	**Grain Yield**
kg ha^{-1}	t ha^{-1}		--------------- kg ha^{-1} ---------------		
0	4.2	120	187.0a	19.7a	1777a
0	8.4	120	185.9a	18.6a	2026a

Table 72. Effect of lime and green manure, 1999 Peanut, Ilagan core experiment.

Inputs				
Lime	**Green Manure**	**N uptake**	**P uptake**	**Grain Yield**
	t ha^{-1}		kg ha^{-1}	
4.8	0	174.6	16.8	1793
0	5	163.0	13.5	1565
4.8	5	196.5	20.6	1992

Table 73. Contrasts for lime and green manure effects, 1999 Peanut, Ilagan core experiment

Contrasts	**Treatment comparisons**	**Mean Differences**		
		Total N uptake	**P uptake**	**Grain Yield**
Effect of lime when green manure is also applied	T15 vs. T14	33.51ns	7.15*	426.57*
Effect of green manure when lime is also applied	T15 vs. T3	21.92ns	3.83*	198.94ns
Lime only vs. green manure only	T3 vs T14	11.60ns	3.32ns	227.63ns

**, significant at 1%, *significant at 5%, ns, not significant

Table 74. N response, soybean, Ilagan, Isabela, 2000.

Inputs					
N	**Lime**	**P**	**N uptake**	**P uptake**	**Grain yield**
kg ha^{-1}	t ha^{-1}		--------------- kg ha^{-1} ---------------		
0	4.2r*	50f*+60r	103.5a	5.5a	1732a
30	4.2r	50f+60r	112.6a	6.3a	1836a
135	8.4r	50f+60r	126.0a	6.1a	2044a

*f=freshly applied, r=residual from 1999 Peanut application

Table 75. P response, soybean, Ilagan, Isabela, 2000.

Inputs			Mehlich 1 P				
N	Lime	P	at planting	after harvest	N uptake	P uptake	Grain yield
kg ha^{-1}	t ha^{-1}	kg ha^{-1}	ug g^{-1}			kg ha^{-1}	
30	4.2r	0	4.0	1.1	45.8c	2.3c	551c
30	4.2r	25f+30r	4.6	4.3	83.0b	7.8b	1466b
30	4.2r	50f+60r	8.2	6.2	112.6ba	11.4a	1836ba
30	4.2r	100f+120r	12.4	13.0	130.9a	13.6a	2183a

r=residual from 1999 Peanut application

Table 76. 2000 Soybean, Ilagan Lime response

Inputs			Mehlich 1-P			
N	Lime	P	after harvest	N uptake	P uptake	Grain Yield
kg ha^{-1}	t ha^{-1}	kg ha^{-1}	ug g^{-1}	---------- kg ha^{-1} ----------		
0	4.18r	100f+120r	15.5a	133.2a	14.0a	2072a
0	8.37r	100f+120r	18.1a	128.4a	14.2a	2118a

r=residual from 1999 Peanut application

Table 77. Effect of lime and green manure plots 2000 Soybean, Ilagan core experiment

Inputs		Mehlich 1-P			
Lime	Green Manure	after harvest	N uptake	P uptake	Grain Yield
----- t ha^{-1} -----		ug g^{-1}	---------- kg ha^{-1} ----------		
4.2	0	5.5	103.5	10.1	1578
0	5	4.9	87.9	9.2	1361
4.2	5	7.7	123.6	12.7	1947

Table 78. Contrasts , 2000 Soybean, Ilagan core experiment

	Treatment	Mean Differences		
Contrasts	comparisons	N uptake	P uptake	Grain Yield
Effect on lime given green manure is present	T15 vs. T14	35.66*	3.49**	586.00**
Effect of green manure given lime is present	T15 vs. T3	20.13*	2.63**	369.13**
Lime only vs. green manure only	T3 vs T14	15.53ns	0.86ns	216.87*

**,,significant at 1%, *,significant at 5%, ns, not significant at 5%

Table 79. N response, 2000 Mungbean, Ilagan

Inputs					
N	Lime	P	N uptake	P uptake	Grain Yield
kg ha^{-1}	t ha^{-1}		kg ha^{-1}		
0	0.5f +4.18r2	60f+50r1+60r2	46.9a	5.0a	1042b
30	0.5f+ 4.18r2	60f+50r1+60r2	60.0a	6.8a	1443a
210	0.5f +8.37r2	90f+50r1+60r2	52.9a	7.1a	1221ab

f=freshly applied, r1=residual from 2000 Soybean, r2=residual from 1999 Peanut

Table 80. P response, 2000 Mungbean, Ilagan

Inputs			Mehlich 1-P				
N	Lime	P	bef. planting	after harvest	N uptake	P uptake	Grain Yield
kg ha^{-1}	t ha^{-1}	kg ha^{-1}	ug g^{-1}			kg ha^{-1}	
30	0.5f+ 4.18r2	0	1.06 b	2.30	19.5b	1.5b	487c
30	0.5f +4.18r2	30f+25r1+30r2	4.28 b	5.80	49.3a	5.2a	908b
30	0.5f +4.18r2	60f+50r1+60r2	6.25 b	9.17	60.0a	6.8a	1443a
30	0.5f +4.18r2	90f+100r1+120r2	13.02 a	16.11	55.4a	6.2a	1301a

Table 81. Lime response, 2000 Mungbean, Ilagan

Inputs					
N	Lime	P	N uptake	P uptake	Grain Yield
kg ha^{-1}	t ha^{-1}	-------------------- kg ha^{-1} --------------------			
0	0.5f +4.18r2	100r1+120r2	47.5a	5.4a	1105a
0	4.0f +8.37r2	100r1+120r2	55.9a	6.4a	1261a

Table 82. Effect of lime and green manure plots 2000 Mungbean, Ilagan core experiment

Inputs		Mehlich 1 P			
Lime	Green Manure	after harvest	N uptake	P uptake	Grain Yield
----- t ha^{-1} -----		ug g^{-1}	------------- kg ha^{-1} -------------		
4.8	0	11.00	46.9	45.0	825
0	5	9.12	53.1	5.4	957
4.8	5	11.10	53.5	5.9	907

Table 83. Contrasts, 2000 Mungbean, Ilagan core experiment

	Treatment	Mean Differences		
Contrasts	comparisons	N uptake	P uptake	Grain Yield
Effect on lime given green manure is present	T15 vs. T14	0.38ns	0.53ns	-49.62ns
Effect of green manure given lime is present	T15 vs. T3	6.65ns	0.96ns	81.90ns
Lime only vs. green manure only	T3 vs T14	-6.27ns	-0.43ns	-131.53ns

** significant at 1%, * significant at 5%, ns not significant at 5%

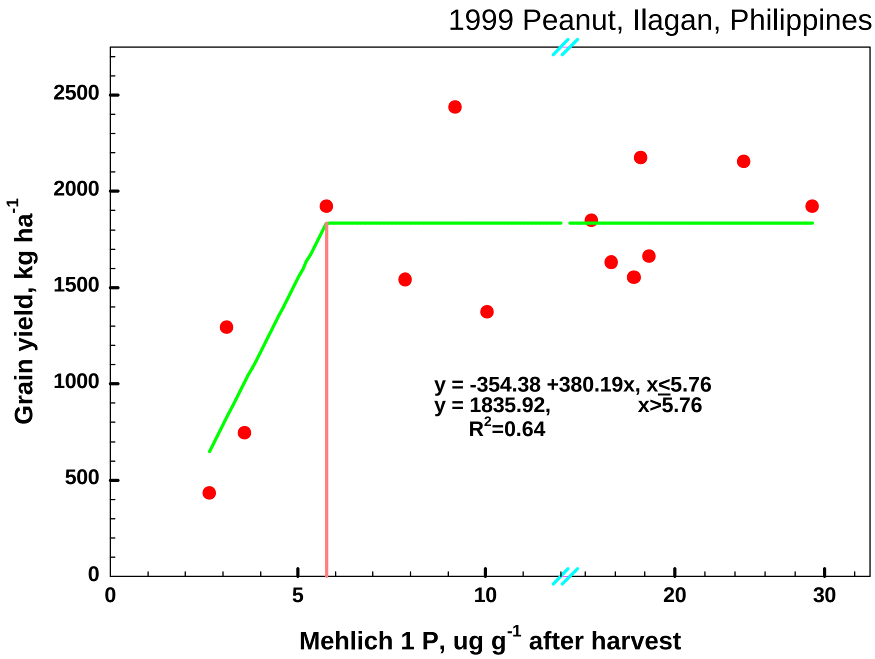

Figure 15. 1999 Peanut response to increasing P level, Ilagan Core Experiment, Philippines.

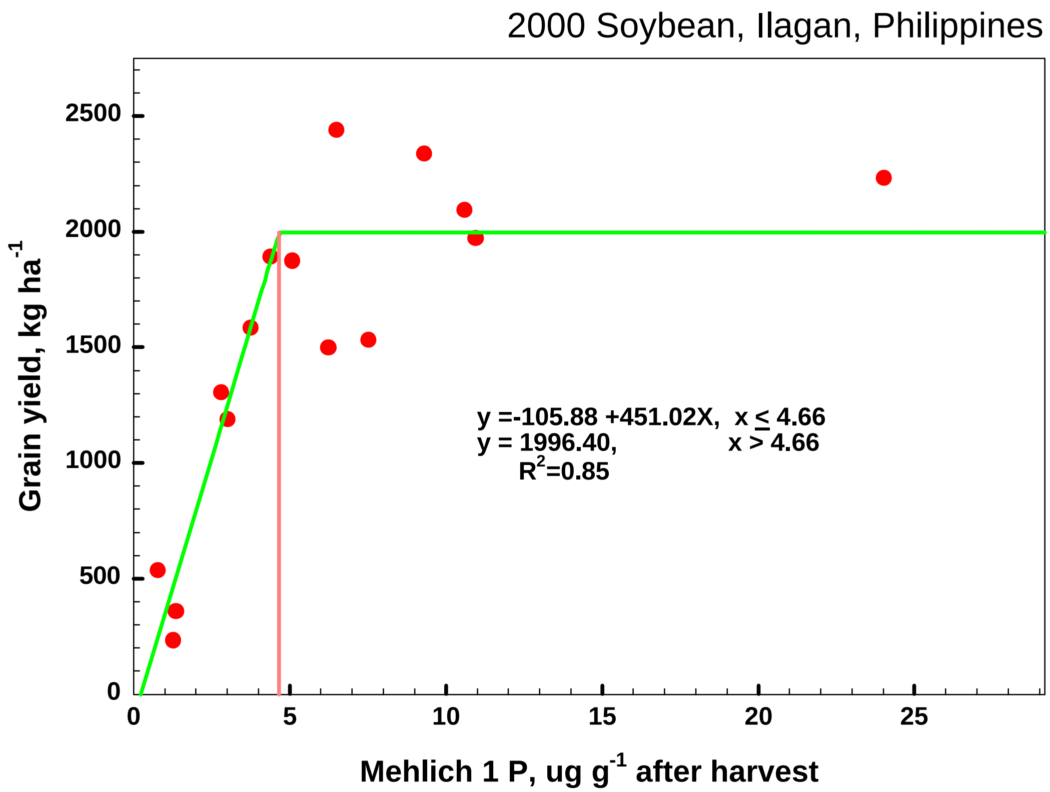

Figure 16. Response of soybean to increasing P level, 2000 soybean experiment, Ilagan, Philippines.

External Funding and Support

- Costa Rica - support in kind from the Univ. Costa Rica in terms of salaries, laboratories and soil/plant analyses, transportation and administrative services are estimated by our collaborators to be $150,000 this year. The agribusiness company DEMASA of Costa Rica and small farmers provided in-kind support by allowing access and harvests of peach palm in their properties. Support in kind from the Ministry of Agriculture, via the 'Los Diamantes' Experiment Station for salaries, experiment maintenance and field supplies/materials are estimated to be $55,000 this year. Local farmer support for the on-farm P fertilization trial is conservatively estimated at $5,000. Total support to the project by collaborators in Costa Rica is conservatively estimated at $210,000.
- Mali - Contributions of time and field and laboratory resources by the Mali collaborators to conduct the research trials, provide the chemical analyses, and perform statistical analysis and interpretation of the data.
- Philippines - Contributions in travel and time costs, experiment establishment/maintenance by IRRI are estimated at$5,000. Time spent by collaborating scientist Dr. Teodula M. Corton (25% of her time). In addition, the use of the laboratory facilities of PhilRice, use of equipment and vehicle for visiting the site. Time also of collaborators from DA-Ilagan Experiment Station (20% of their time).

Travel and Meetings Attended

- Adrian Ares - ASA-CSA-SSSA Annual Meetings, 5 Nov. – 10 Nov., Minneapolis.
- Loyd Hossner - travel to Mali to assist IER collaborators to organize data collected in 1998-1999 and discuss plans for the 2000 crop year. May 22-June 3.
- Jocelyn Bajita - travel to Philippines to conduct field research on diagnosis and alleviation of Mn toxicity in acid upland soils as part of Ph.D. program at the Univ. of Hawaii. May 15-August 22.
- Eloy Molina - travel to Hawaii to work with Univ. Hawaii and N.C. State Univ. collaborators on field and laboratory data for trials in Costa Rica on peach palm nutrient management. July 2-15.
- Frank Hons - travel to Mali to assist IER collaborators in planting experiments for the 2000 crop year and collect pending data from the 1998-1999 crop seasons. August 12-19.
- Adrian Ares - travel to Costa Rica to work with collaborators on soil microbial and organic P analysis, verify allometric relations for peach palm biomass and nutrient accumulation, and measure below ground biomass storage in mature plantations. September 9-24.
- Fred Cox - travel to Costa Rica to work with collaborators on laboratory and field trials related to P management for peach palm; travel to Ecuador to review and discuss soil P management data with Dr. Espinosa (PPI-Potaphos). September 17-18.
- L. R. Hossner and F. M. Hons traveled to the American Society of Agronomy meetings in Minneapolis, Minnesota, to participate in technical meetings and discuss international programs with Soil Management CRSP personnel.
- Thomas George - ASA-CSA-SSSA Annual Meetings, 5 Nov. – 10 Nov., Minneapolis.

Relevant Publications, Reports and Presentations at Meetings

Annual Philippines Research and Development Symposium, 2000, 2001. (National Meeting).

Ares, A. 2000. Report on trip to Costa Rica. Decision Aids for Integrated Soil Nutrient Management Project. 7p. (http://intdss.soil.ncsu.edu/sm-crsp/Download/Trip_Reports/Ares_CRica_0900.pdf).

Ares, A., N.P. Falcao, R.S. Yost, K. Yuyama, E. Molina and C.R. Clement. Soil and foliar nutrient analysis as diagnostic and predictive tools in perennial tree crops. Agron. Abstr. p. 353.

Ares, A., J.P. Quesada, J. Boniche and R.S. Yost. 2000. Allometric relationships for *Bactris gasipaes* Kunth in heart-of-palm production agroecosystems of Costa Rica. Agron. Abstr. p.56.

Ares, A., J.P. Quesada, J. Boniche, R.S. Yost, E. Molina, J. Smyth. Allometric relationships for *Bactris gasipaes* Kunth in heart-of-palm production agroecosystems in Costa Rica. (To be submitted to the Journal of Agriculture Science).

Ares, A., J. Boniche, E. Molina, R.S. Yost (2000). Biomass, nutrients and carbon stores as affected by age and spacing on *Bactris gasipaes* stands for heart-of palm in Costa Rica (To be submitted to Field Crops Research).

Blanton-Knewtson, Sharon. 2000. Nitrogen and phosphorus dynamics in tropical soils of Mali, West Africa. Master of Science Thesis. Texas A&M Univesity. College Station, TX. 173 p.

Cox, F. 2000. Report on travel to Costa Rica and Ecuador. Decision Aids for Integrated Soil Nutrient Management Project. 12p. (http://intdss.soil.ncsu.edu/sm-crsp/Download/Trip_Reports/Cox_TripRpt_900.pdf).

Doumbia, M.D., A. Sidibé, A. Bagayoko, A. Bationo, R. A. Kablan, R.S. Yost, L.R. Hossner et F.M. Hons. 2001. Recommandations Specifiques d'engrais: Calibration et Validation du Module Phosphore de Numass. African Crop Science (in review)

George, T., J. Quiton and R. Yost .2000. Determining critical soil phosphorus levels for upland crops. Poster presented at the ASA-CSA-SSSA Annual Meetings, 5 Nov.- 10 Nov., Minneapolis.

Hons, F. 2000. Report on trip to Mali. Decision Aids for Integrated Soil Nutrient Management Project. 3p. (http://intdss.soil.ncsu.edu/sm-crsp/Download/Trip_Reports/Hons_Mali_0800.pdf).

Hossner, L. 2000. Report on trip to Mali. Decision Aids for Integrated Soil Nutrient Management Project. 2p. (http://intdss.soil.ncsu.edu/sm-crsp/Download/Trip_Reports/Hossner_Mali_0500.pdf).

Kouyate, Zoumana, Kathrin Franzluebbers, Anthony S.R. Juo, and Lloyd R. Hossner. 2000. Tillage, crop residue, legume rotation, and green manure effects on sorghum and millet yields in the semiarid tropics of Mali. Plant and Soil. 225:141-151.

Molina, E., A. Ares, R.S. Yost and T.J. Smyth. 2000. Biomass and nutrient accumulation through time in Bactris gasipaes, Kunth, agroecosystems in Costa Rica. Agron. Abstr. p. 270.

Toure, A., S.B. Coulibaly, M. D. Doumbia, D. T. Rosenow, G.C. Peterson, S. Sidibe, A.B. Onken, and L. R. Hossner. 2001. Sorghum growth in acid soils of West Africa: Genotype screening. African Crop Science Journal. (In Press)

Yost, R., A. Ares. (2000) Nutrient management decision support systems for tree crops. Proc. Symposium on Soil and Site Productivity for Forestry in Hawaii (In press).

Yost, R., A. Ares. (2000) Phosphorus and lime needs of trees in highly weathered soils. Proc. Symposium on Soil and Site Productivity for Forestry in Hawaii (In press).

Objective 2: Improve the diagnosis and recommendations for acidity and nutrient problems by identifying and resolving knowledge gaps through extensive literature reviews and, when necessary, developmental research.

Output 1 Enhancing the knowledge base for the acidity decision support system - collecting, developing and synthesizing soil, plant and management information to improve the diagnosis and recommendations of location-specific problems related to the soil acidity syndrome.

The current knowledge base on acidity in NuMaSS does not predict the rate of movement of basic cations into acid subsoils from surface-applied liming materials. This limits our ability to recommend management strategies for alleviating acidity constraints below the depth of lime incorporation, or properly accounting for the economic value of improved crop rooting depth as lime reaction products move into the subsoil. The introduction and movement of Ca and Mg into subsoils is a major consideration for sustained productive use of the acid, sandy soils in the African Sahel. The acidity knowledge base needs to be expanded to evaluate soil conditions with limited Ca and/or excess Mn. The consequences of using lime materials low in Mg on soil Mg availability also need to be added to the acidity module knowledge base.

Funding for all activities for improving the acidity module knowledge base is provided through the end of the year 3, but completion dates extend through year 4. Investigations related to basic cation (lime) movement were funded during years 1 and 2, but information continues to be collected in subsequent years. Investigations related to Ca and Mg deficiencies and/or Mn toxicity continue through year 3 in the Sahel and year 4 elsewhere.

<u>Lead Investigators and Contributors</u>

Jot Smyth (N.C. State) provides overall coordination to activities related to the acidity module. Investigations on basic cation movement prediction parameters are under the direction of David Bouldin (Cornell) and Anthony Juo (Texas A&M) directs field and lab work on this task in the Sahel. Nguyen Hue (Hawaii) and Smyth provide direction to lab, greenhouse and field investigations in Costa Rica and the Philippines related to diagnosis of Ca and Mg deficiencies, Mn toxicity, and lime equivalence of organic inputs. All team members are involved in efforts to review and assemble pertinent knowledge in the published and "grey" literature. Additional contributors to this output during year 3 are listed according to their respective institutions:

University of Costa Rica/Costa Rica - Alfredo Alvarado, Rafael Salas, Lidieth Uribe and Eloy Molina

Institue d'Economie Rurale/Mali - Mamdou Doumbia (Sotuba Station); Zoumana Kouyate and Adama Coulibaly (Cinzana Station)

Texas A&M University - Yuji Nino graduate student

IITA/Nigeria - G. Tiau

<u>Progress</u>

1. *Movement of Ca and Mg in a Kaolinitic Alfisol under maize in the humid tropics* - (conducted by Yuji Nino of Texas A&M and G. Tian of IITA with support from A. Juo and Frank Hons from Texas A&M) This study was conducted in Ibadan, Nigeria to determine the extent of acidification due to N fertilization and movement of cations (Ca and Mg) displaced from the surface layers of an Oxic Paleustalf (Egbeda series). The N sources included two inorganic N fertilizers, urea (UA) and ammonium sulfate (AS), and one green manure, *Alchornea cordofolia* (Alc). The decline in surface soil pH after one year of cropping (2 seasons) followed the order of AS>(AS+Alc)>UA . (UA+Alc)>Alc>Control. The pH (H_2O)

of the AS treatment decreased from 6.2 to 4.5. Acidity induced by inorganic fertilizers decreased exchangeable Ca and Mg in the surface soils. Magnesium leached more rapidly than Ca. Addition of organic input retarded the leaching of Ca, Mg, and NO_3-N.

Results - Maize grain yield is shown in Fig. 1. Both organic and inorganic N inputs gave significantly higher grain yields than the control for both seasons. The combination of AS+Alc treatment gave the highest grain yield. The yield response due to the three N sources were not statistically significant. The second season maize yield from the AS treatment was not affected even though soil pH was lowered to 4.5.

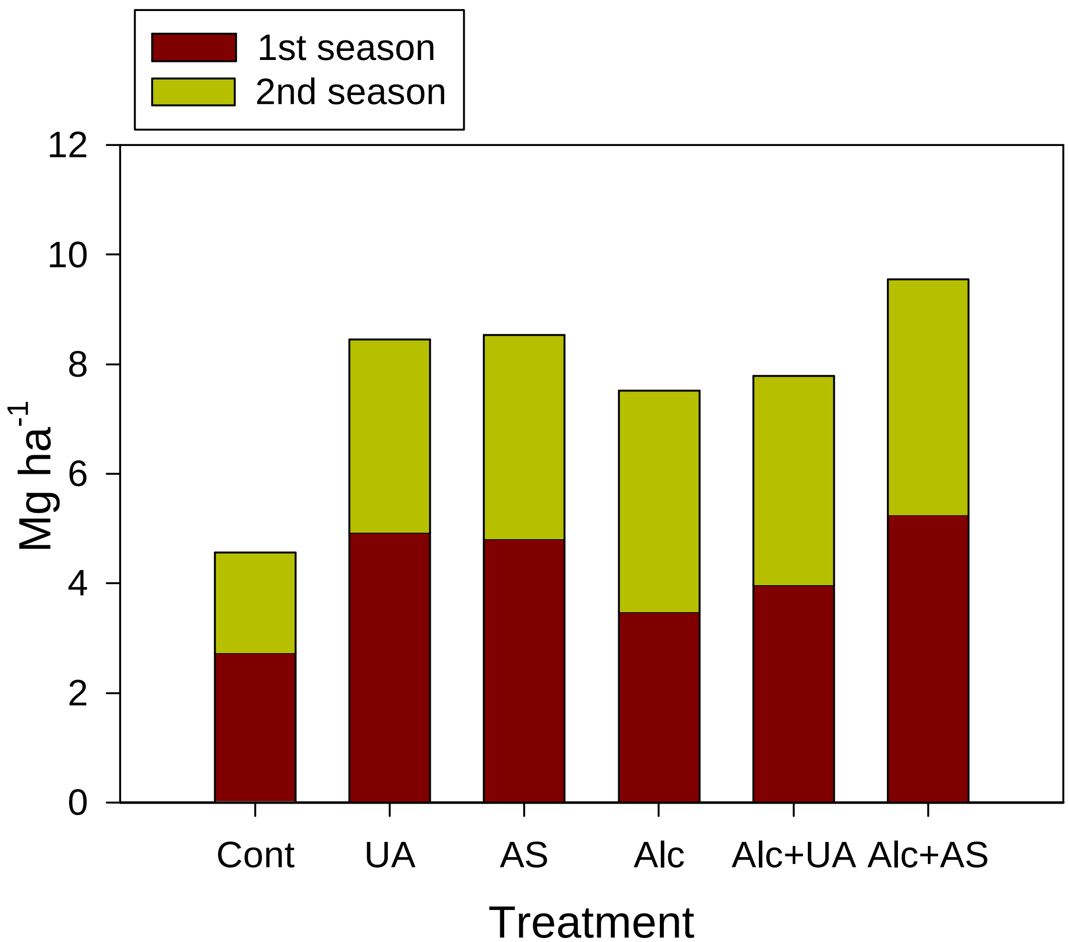

Figure 1. Maize grain yields during the main and minor seasons in 1999

Changes in surface soil pH (0-2.5 cm) after application of different N sources are shown in Fig. 2. The pH (H_2O) of the AS treatment decreased from 6.2 before planting to 4.5 after two cropping seasons. Soil acidification among the different treatments followed the order of AS>Alc+AS>UA . Alc+UA>Alc>Control. In the subsequent depths up to 30 cm, the treatment effects were significant in each depth. Control and Alc plots showed the least decrease in pH. Changes in pH due to AS was significantly different from other treatments in 0-20 cm (p=.05).

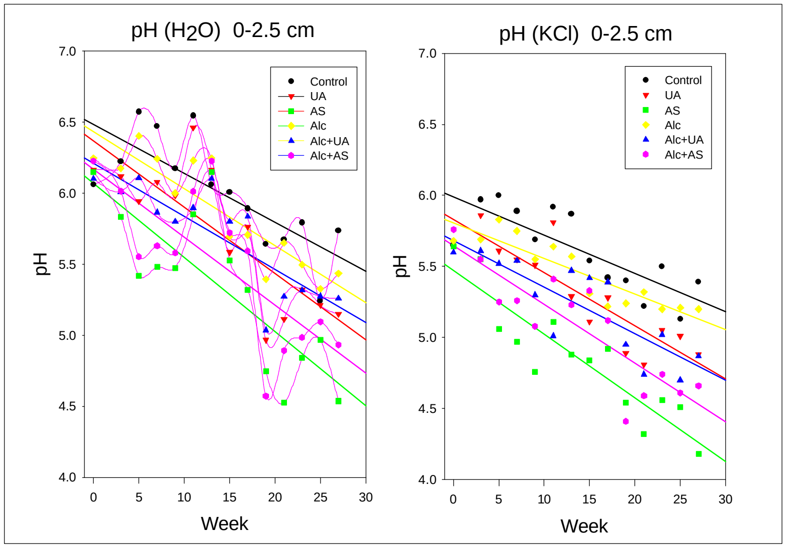

Figure 2. Changes in surface soil pH (0-2.5 cm) after application of different N sources.

The amounts of exchangeable Ca and Mg at different depth at the beginning and the end of the cropping season are shown in Fig. 3. Acidity induced by inorganic fertilizers significantly decreased exchangeable Ca concentration, especially in the 0-2.5 cm and 2.5-5 cm depths. The Alc treatment increased exchangeable Ca in the surface 5 cm layer. Changes in exchangeable Mg showed a similar trend as that of Ca. Vertical distribution of exchangeable Ca and Mg data from soil samples taken at 3 and 5 WAP (not shown), indicating more rapid leaching of Mg than Ca. Nitrate N movement (Fig. 4) corresponded with Ca and Mg movement. Increase of exchangeable Ca in the surface layer in the control treatment may be due to P fertilizer (TSP) application and organic matter decomposition.
Conclusions - This study showed that rapid acidification occurred in kaolinitic Alfisols as a result of N fertilizer applications. Incorporation of Alchornea residue retarded the rate of acidification and helped prevent rapid leaching of Ca, Mg, and NO_3^--N during cropping.

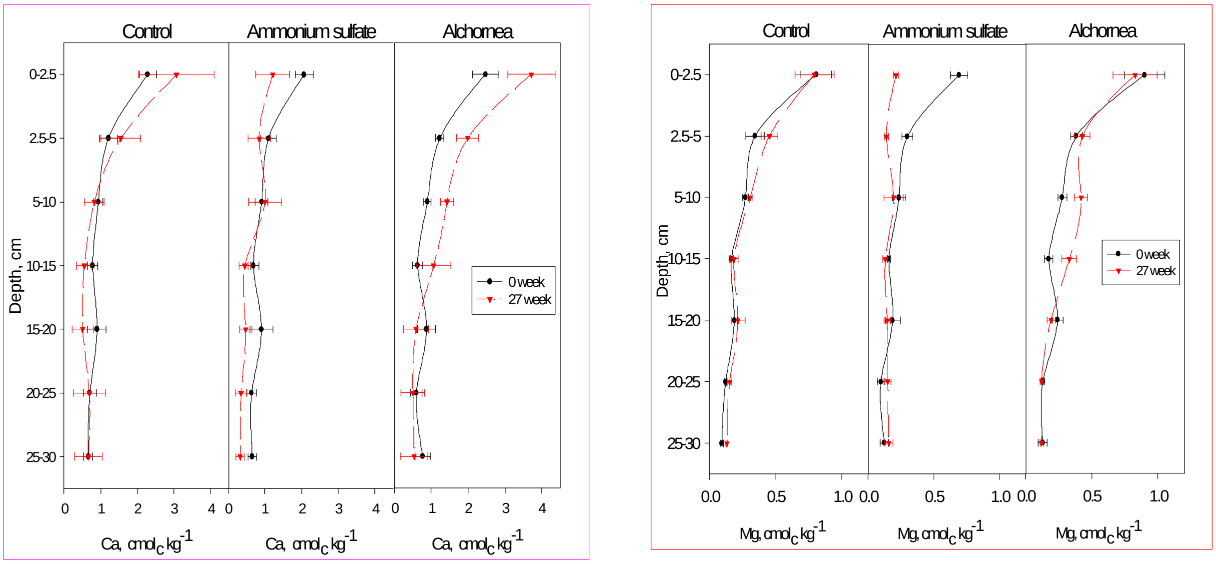

Figure 3. Amounts of exchangeable Ca and Mg at different depths at the beginning (week 0) and the end of the cropping seasons (week 27).

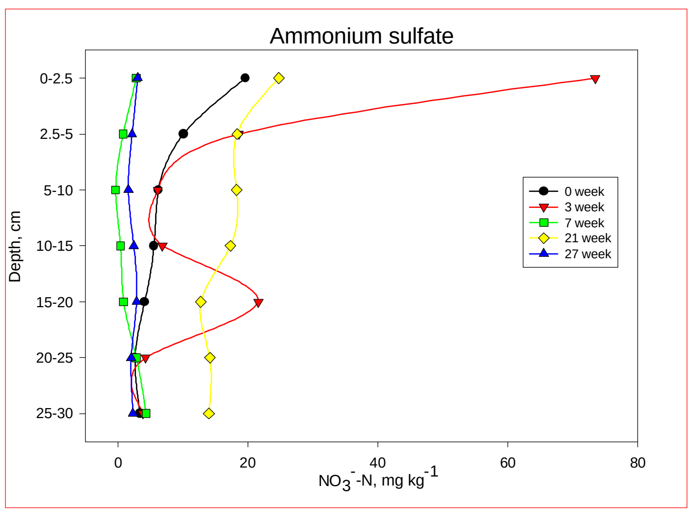

Figure 4. Nitrate N movement with time and depth.

2. *Calcium and Magnesium Movement in Sandy and Clayey Millet Soils of the Sudano-Sahelian Region* - (supervised by Adama Coulibaly, M.D. Doumbia, Aminata Sidibi, A. Bagayokol, M.A. Diarra, and J. Keita of IER, Mali with support from Lloyd Hossner and Frank Hons) An increase in the acidity of soils in pearl millet (*Pennisetum glaucum* (L. Br.) growing areas of the Sudano-Sahelian Zone of Mali is a major threat to the sustainability of agricultural production and subsequently to the food security of the entire region. Potential sources of soil acidification include continuous cropping of dryland cereal (in most cases millet and commonly over 35 years), return of little or no crop residue, an extreme decline in soil organic matter content, eolian and water erosion of soil, and the lack of appropriate management techniques. Pearl millet ranks as the staple cereal in Mali with an average

consumption rate of 86 kg per capita per year. Approximately 1.7 million hectares are devoted to millet production with low yields in the range of 450 to 735 kg ha^{-1}.

Low crop yield performance in the Sudano-Sahelian region are usually associated with soils that are chemically characterized by limited organic matter content, low pH, low buffer capacity, and low effective cation exchange capacity (ECEC). Management techniques to alleviate aluminum (Al), manganese (Mn), and iron (Fe) toxicities in acid soils and increase exchangeable calcium (Ca) and magnesium (Mg) for millet farmers are not commonly practiced. Local materials (sources of Ca and Mg) with some liming potential are available in Mali. This study focused on evaluating selected physical and chemical properties of different sources of locally available potential lime materials and their effect on soil properties and subsequent grain and stover yields.

Locally available materials included in the study were ash from millet stover, poultry manure, farm manure (cow and small ruminants), profeba (a locally manufactured organic manure mixed with an imported active ingredient), gypsum, Diamou lime, Telemsi natural rock phosphate, and guala. Selected physical characteristics of the local Ca source materials are in Table 1. Among all sources, Diamou lime had the highest percentage of $CaCO_3$. The lowest $CaCO_3$ equivalent was associated with the ash, gypsum, poultry and farm manure, profeba, and the TPR. Although the guala has 27.7% Ca, the Ca is not present as $CaCO_3$. Materials such as lime, Telemsi rock phosphate, and ash had pH values greater than 9.0. The pH of lime, poultry manure, and farm manure was not affected by particle size, however, high pH values were associated with the finest particle fractions of the profeba, ash, and Telemsi rock phosphate. The highest P contents were associated with the Telemsi rock phosphate and the poultry and farm manures and the least from the ash, guala, lime, and the gypsum.

Table 1. Some chemical characteristics of locally available calcium sources in Mali.

Material	pH	N	P_2O_5	Ca	Mg	K	$CaCO_3$
		---------------------------------	---------------------------------	%	---------------------------------	---------------------------------	
Ash	10.6	0.26	0.53	0.25	0.93	1.54	1.8
Poultry Manure	7.2	3.76	4.74	1.93	0.40	1.16	1.4
Farm Manure	7.7	1.97	2.24	0.44	0.94	1.93	0.1
Profeba	7.4	1.63	2.36	0.16	0.31	0.52	0.0
Gypsum	8.2	0.00	0.03	26.70	0.36	0.08	2.0
Lime	13.0	0.00	0.05	45.80	5.65	0.00	60.4
Tilemsi PR	9.6	0.03	23.20	50.00	2.62	0.02	1.0
Guala	8.2	0.00	0.06	27.70	0.83	4.00	0.0

A field experiment was conducted during the 1998 and 1999 growing seasons on two millet soil types (sandy and clayey) located at the Cinzana Agronomic Research Station in the Sudano-Sahelian Region of Mali. The sandy soil is located on the summit of the toposequence and the clayey soil is located on the toeslope. These soils are representative of soils encountered in the region. Calcium bearing materials (lime, Telemsi rock phosphate (PNT), and gypsum) were applied at liming rates (Lr) of 0Lr, 0.5Lr, 1.0Lr, and 2.0Lr. PNT and gypsum were applied to provide equal amounts of Ca as with lime. The cropping system was a continuous monoculture of millet on both soils. The materials were mixed with the surface soil at application. The cumulative rainfall for the 1998 growing season (841.7 mm) and the 1999 season (999.3 mm) exceeded the 10 year average rainfall of 697.8 mm.
The available soil Ca level of the two soils as a function of depth is presented in Figure 5. The clayey soil has a higher Ca concentration in the deeper horizons while the sandy soil tends to have decreasing Ca with depth. The clayey soil contains more exchangeable soil Ca than the sandy soil at any depth. The difference between the two soils is probably related to their origin and cropping history. The clayey soil is formed from alluvial deposits of the Bani River and contains calcareous nodules. This soil has a moderate clay content (40%), higher pH (5.98), and very low acid saturation. The sandy soil has low clay content, a low pH (4.91), and higher exchangeable acidity. There is no evidence of Ca movement below the 7.5 cm depth for either soil.

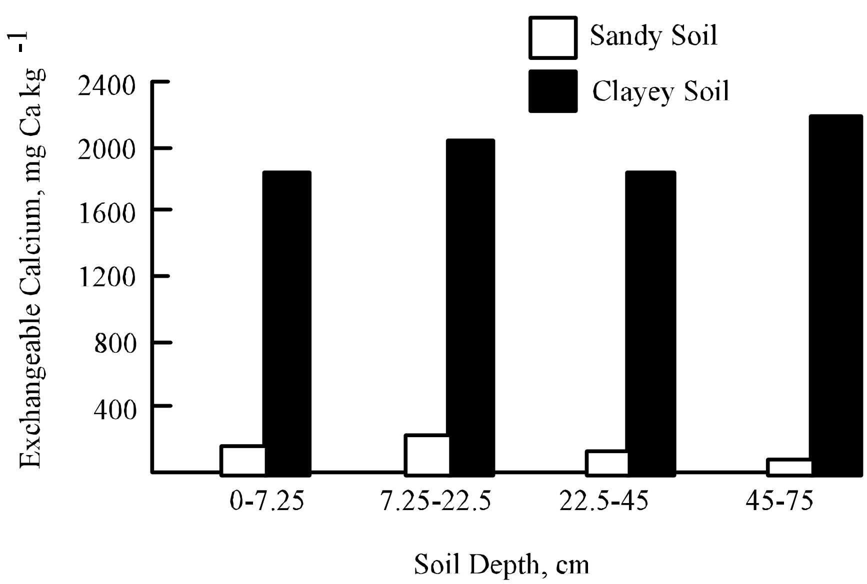

Figure 5. Soil Ca as influenced by soil type and depth at Cinzana, Mali (1997-1999)

Soil pH in the 0-7.5 cm portion of the profile due to lime and Telemsi rock phosphate application increased significantly (Figure 6). There was no significant change in pH due to gypsum application compared to the control. Similar trends in pH due to application of materials were apparent in the sandy and clayey soils.

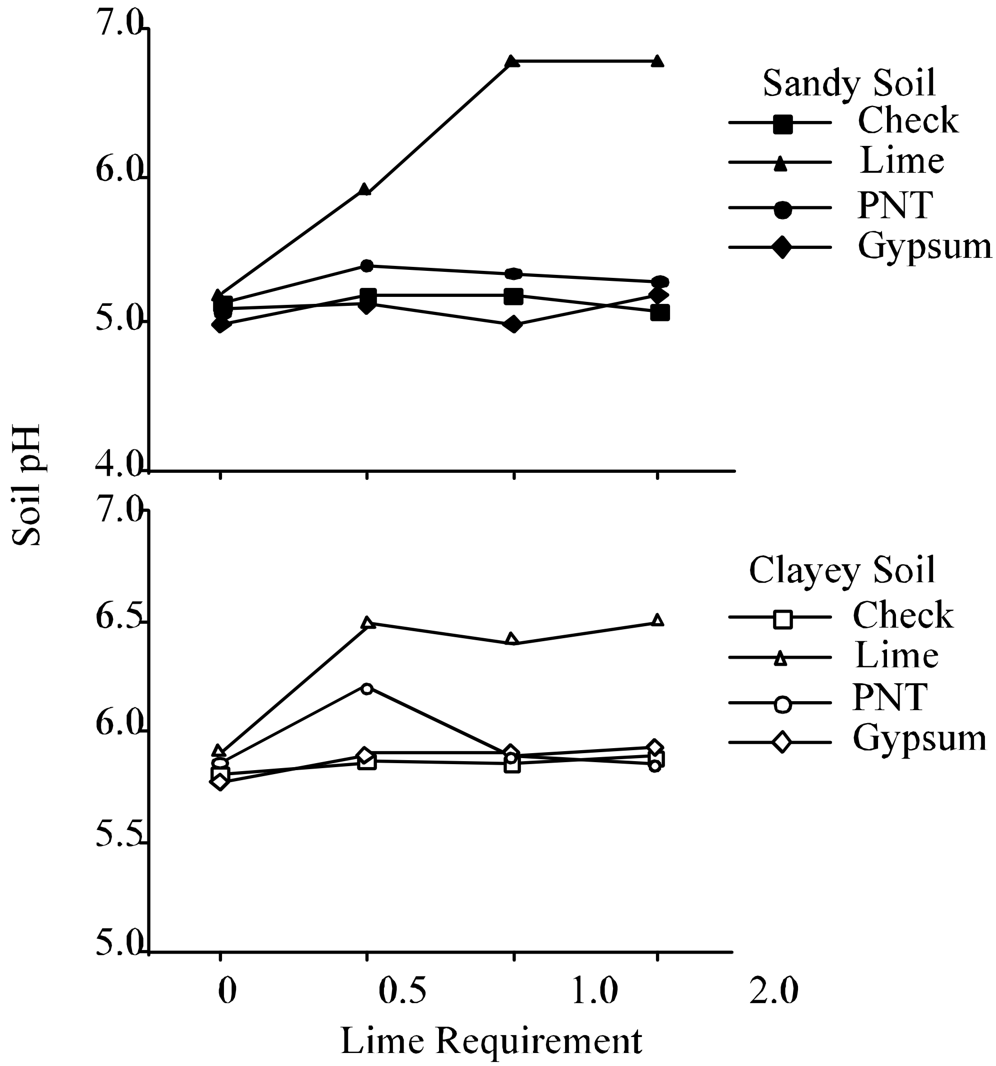

Figure 6. Sandy and clayey soil pH (0-7.5 cm depth) as influenced by lime source and rate at Cinzana, Mali.

The higher grain yield in 1998 was on the sandy soil compared to the clayey soil. In 1999, grain yield on the clayey soil was greater than on the sandy soil but the difference was not statistically significant (Table 2). This crop performance pattern appears to be the result of an interaction between cumulative rainfall by soil type. Higher millet yields in years with low rainfall are usually associated with sandy soil. Sandy soils have higher water infiltration, less runoff, and retain more available moisture than clayey soil during the growing season. The cumulative rainfall for the 1998 growing season (841 mm) and the1999 growing season (900 mm) exceeded the 10 year average rainfall of 677 mm. There was not an increase in grain yield due to Ca application, however, the highest yields were associated with Telemsi rock phosphate applications. This was apparently a response to applied P.

Table 2. Millet yield in 1998 and 1999 as influenced by soil and source and rate of Ca applied in 1998.

Treatment	Millet Grain Yield 1998	1999
	------------------- kg ha^{-1}	-------------------
Soil Means		
Sandy	2132 a	4408 a
Clayey	1590 b	4837 a
Ca Source Means		
Check	1735 ab	4916 ab
Diamou Lime	1675 ab	4225 b
Telemsi PR	2153 a	4991 a
Gypsum	1862 ab	4358 b
Calcium Rate Means		
0 x Lime requirement (LR)	1635 b	4589 a
0.5 x LR	1823 ab	4636 a
1 x LR	1871 ab	4760 a
2 x LR	2104 a	4505 a
Analysis of Variance		
Soil x Source	NS	NS
Soil x Rate	S	NS
Source x Rate	NS	NS
Coeff. Variation (%)	39	26

3. *H/Al rhizotoxicity and Ca/Mg requirements for peach palm root growth* - (supervised by Rafael Salas at UCR with support from Nguyen Hue and Jot Smyth) due to problems in applying some of the lime treatments to soil, the desired neutralization of acidity was not achieved. The experiment is being repeated and results will be provided during the coming year.
Through our extensive evaluation network we learned of and gained access to a similar investigation conducted at the University of Viçosa in Brazil (Pachêco, R.G. 1997. Growth of peach palm seedlings (*Bactris gasipaes* H.B.K.) in response to liming and soil Ca:Mg ratios, and nitrate:ammonium ratios in nutrient solutions with Al. Ph.D. Thesis, Federal University of Viçosa, Minas Gerais, Brazil. 102 p.). In studies with peach palm seedling in ¼ Hoagland nutrient solutions plant top and root growth inhibition with increasing Al

concentrations from 0 to 30 mg L^{-1} were considerably less than responses observed for row crops. Peach palm seedling response to lime was also evaluated in pots with subsoil material from an Oxisol initially containing 0.2 cmol L^{-1} of Ca, traces of Mg and 72% Al saturation. Shoot dry weight increased by 10% relative to the unlimed treatment with the lowest lime rate which reduced % Al saturation to 37 and raised soil pH to 4.5. At higher rates of lime, shoot dry weight was less than that for the control regardless of the Ca:Mg ratios in the lime material which ranged 0.5:1 to 8:1. These results lend support to our hypotheses that peach palm tolerance to acidity is high and requirements for Ca and Mg are less than for most row crops.

4. *NuMaSS acidity diagnosis: prediction of acid saturation % from soil pH* - the diagnosis component of NuMaSS uses information about field location, land use history, previous crop yields, indicator plants and visual plant symptoms to predict whether there will be a nutrient constraint for the targeted crop. Soil chemical data is not required for a diagnosis, but will be considered and contribute to the assessment of constraints when provided. Users evaluating NuMaSS prototypes have suggested consideration of soil pH as a substitute for soil data on acid saturation % in the diagnosis of acidity constraints. Calculation of % acid saturation requires soil analytical data for exchangeable cations, namely Ca, Mg, K and either Al or Al+H. In many cases user may have soil pH data, but not the exchangeable cation data. Data from field trails with multiple rates of lime in Inceptisols, Oxisols and Ultisols were investigated for relations between soil pH and acid saturation %. Only data for the first crop cycle in each lime trial was considered. A segmented quadratic-plateau model provided a reasonable fit to the data across all soils (Figure 7). The model predicts that acid saturation % drops to essentially zero (0.5%) at pH 5.9, whereas various studies indicate that this break point occurs around pH 5.5. This relation will be included in NuMaSS 2.0 to enable use of soil pH data in acidity diagnosis. If an acidity constraint is identified for the targeted crop, however, a lime recommendation will only be provided by the prediction module upon user input of acid saturation % data for the soil under consideration.

<u>External Funding and Support</u>

Collaborators at intensive sites are conducting laboratory, greenhouse and field trials on various aspects of soil acidity management. Estimates of their funding contributions to this output are contained in values provided for Objective 1, Output 2.

<u>Travel and Meetings Attended</u>

- Loyd Hossner - travel to Mali to assist IER collaborators to organize data collected in 1998-1999 and discuss plans for the 2000 crop year. May 22-June 3.
- Jocelyn Bajita - travel to Philippines to conduct field research on diagnosis and alleviation of Mn toxicity in acid upland soils as part of Ph.D. program at the Univ. of Hawaii. May 15-August 22.
- Frank Hons - travel to Mali to assist IER collaborators in planting experiments for the 2000 crop year and collect pending data from the 1998-1999 crop seasons.August 12-19.

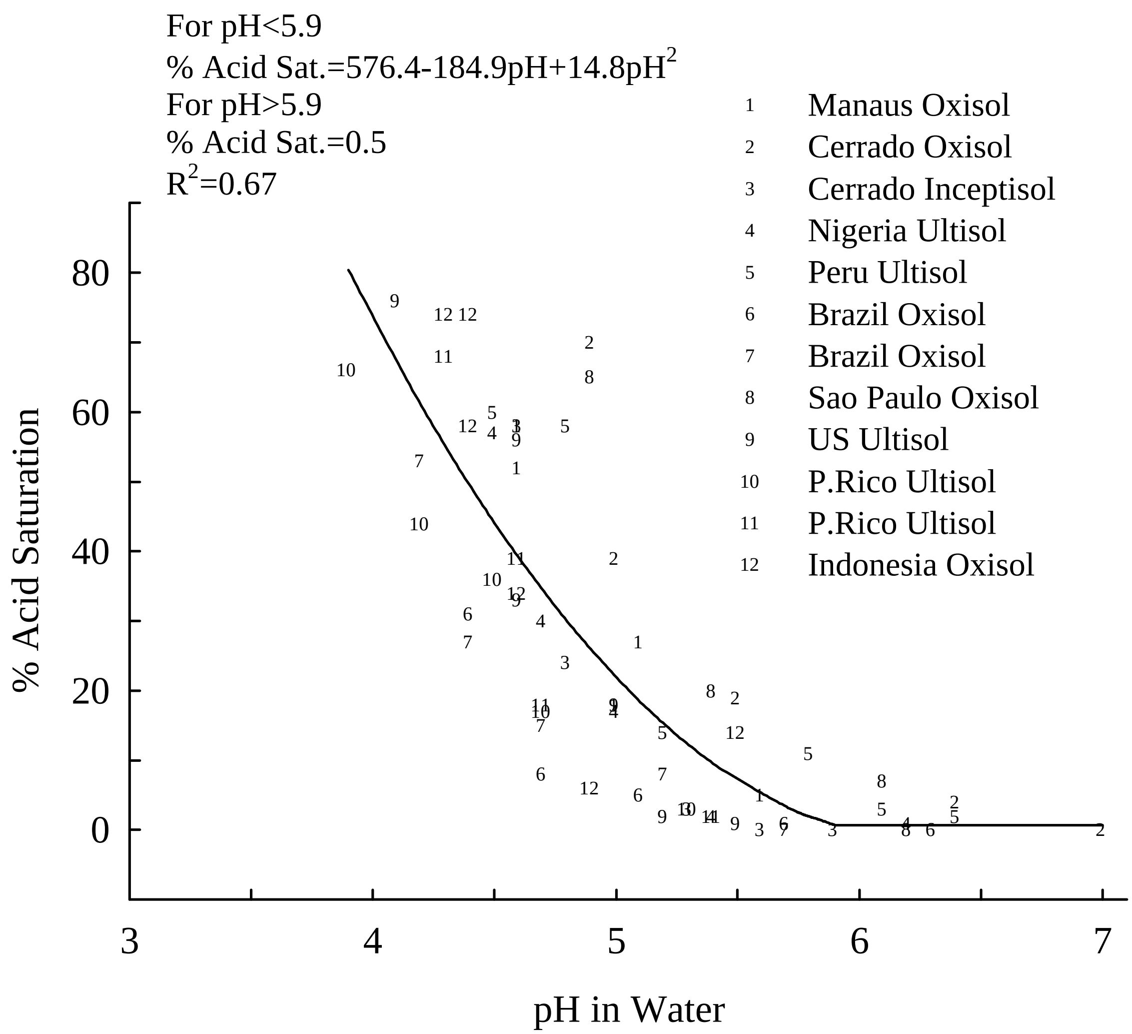

Figure 7. Relation between soil acid saturation % and pH in water for lime trials in Inceptisols, Oxisols and Ultisols.

<u>Relevant Publications, Reports and Presentations at Meetings</u>

Hossner, L. 2000. Report on trip to Mali. Decision Aids for Integrated Soil Nutrient Management Project. 2p. (http://intdss.soil.ncsu.edu/sm-crsp/Download/Trip_Reports/Hossner_Mali_0500.pdf).

Hons, F. 2000. Report on trip to Mali. Decision Aids for Integrated Soil Nutrient Management Project. 3p. (http://intdss.soil.ncsu.edu/sm-crsp/Download/Trip_Reports/Hossner_Mali_0500.pdf).

Nino, Y., G. Tian, F.M. Hons and A.S. Juo. Movement of Ca and Mg in a kaolinitic Alfisol under maize in the humid tropics. Agron. Abstr. p. 57.

Oliveira, F.H., R.F. Novais, T.J. Smyth and J.C. Neves. 2000. Aluminum diffusion in Oxisols as influenced by soil water matric potential, pH, lime, gypsum, potassium chloride and calcium phosphate. Commun. Soil Sci. Plant Anal. 31:2523-2533.

Output 2 Enhancing the knowledge base for the N decision support system - collecting, developing and synthesizing soil, plant and management information to improve the diagnosis and recommendations of location-specific N problems.

Diagnosis and recommendations for N are based on N content of total above ground dry matter production for the targeted crop yield. Fertilizer N requirements are based on the differences between total above ground N needs and the N supplied by soil, manures and atmosphere. Unlike acidity and P, there is no single measure of soil N that allows an evaluation of N source efficiencies and mineralization transfer coefficients among different soils and climates. Coefficients must, therefore, be derived for a variety of soil, crop and climate conditions using prior experimentation whenever possible. Given the size of this task, acquisition and refinement of coefficients will be an ongoing process throughout the entire project. Transfer coefficients for contributions of biologically fixed N need to be categorized in terms of a variety of factors: the legume source and its nutrient requirements, innoculant availability, C constituents, plant age, soil conditions, and timing and method of incorporation. Nitrogen losses need to be either incorporated into to transfer coefficients or predicted.

Milestone events for this output, during the 5-year plan are as follows:

- annual improvement of the database on N transfer and mineralization coefficients to encompass a broader combination of soil, crop and climate conditions;
- prediction of N losses - year 3; and
- guidance for legume management and prediction of BNF contributions - year 5.

Lead Investigators and Contributors

Shaw Reid provides overall coordination to activities related to the N module. During the past year investigators at Cornell and N.C. State University received funding to continue the collection and calibration of N transfer and mineralization coefficients. Funding was also provided to all universities to work on legume management. N.C. State, Cornell and Hawaii also received funding to work on prediction of N losses. However, all other U.S. members of the N group and testing site collaborators have begun to share via correspondence their findings upon searches of the existing literature as well as core experiment activities related to N management. Overseas collaborators contributing to this output during year 3 are listed according to their respective institutions:

Center for Agricultural Research/University of Costa Rica - Alfredo Alvarado, Gabriela Soto and Raphael Salas

Institute d'Economie Rurale/Mali - Mamadou Doumbia and Aminata Sidibe (Sotuba Station); Adama Coulibaly and Zoumana Kouyate (Cinzana Station)

International Rice Research Institute - Thomas George

Philippine Rice Research Institute - Teodula Corton

Progress

1. *Calibrating N coefficients* (Pedro Luna with assistance from Shaw Reid, Dan Israel, Deanna Osmond, Jot Smyth and Michael Wagger) nitrogen recommendations by NuMaSS are based on the following modifed version of the Stanford equation:

$$Nf = (Y*Nc) - [Ns + (Ngm*Cgm) + (Nm*Cm)]/Ef$$

where

Nf = fertilizer N to obtain a target dry matter yield, Y = dry matter yield, vegetative and/or reproductive, Nc = N concentration in dry matter, Ns = soil N taken up by the crop, Ngm = N applied in green manure, Cgm = fraction of N from green manure taken by the crop, Nm = N applied in manure, Cm = fraction of N from manure taken by the crop, and Ef = fraction of fertilizer N recovered by the crop. This report concentrates on summarization of data for Y, Nc, Ns and Ef. Analysis of published N fertilization field trials and assembly of N coefficients on corn, millet and sorghum for Africa, Asia and Latin America continued throughout the year, using a procedure developed with corn data from South America. The procedure entails use of the Mixed Model in SAS to evaluate relations between crop variables and determine whether field trial observations for each commodity can be grouped within or across agro-climatic regions, crop cultivars, and countries. Certain specific relations between crop variables (Table 3) are investigated to determine coefficients for the N recommendations by NuMaSS. Apparent N recovery (ANR) is defined as the difference in total aboveground crop N accumulation between either a fertilizer or green manure treatment and the zero-N treatment. Only treatments within the linear response range were considered for ANR, to avoid unrealistic values with fertilizer N rates that exceeded the optimum level.

Table 3. Relations between crop variables and the corresponding coefficients for NuMaSS N recommendations.

Crop Variable Relations	**Corresponding NuMaSS N Coefficients**
Aboveground N accumulation vs. grain yield	Y*Nc for targeted yields
Apparent N recovery vs. applied fertilizer N	Ef
Green manure N accumulation vs. green manure dry matter yield	Ngm
Apparent N recovery vs. applied green manure N	Cgm

Most of the experiments investigated contained several fertilizer N treatments, including a zero N, and many encompassed several crop cycles. Both local or improved varieties and hybrids were included among the field trials for each commodity. Crop yield response to fertilizer N was also characterized by linear-plateau functions and grouped among experiments using options provided by non-linear regression procedures in SAS. Thus far, only the green manure data for South America has been summarized and very little animal manure data has been found which contains the desirable measurements for this analysis. Many of the experiments did not contain sufficient information to estimate all of the coefficients. Each experiment, with the exception of those in Puerto Rico, was grouped into one of three general agro-climatic regimes: semiarid, wet/dry and humid tropical. Experiments in Puerto Rico were grouped as either “northern coastal plain” (similar to wet/dry) and “interior highlands”. The number of experiments investigated for each commodity are shown in Table 4 by commodity, continental and agro-climatic region along with the countries and soil orders represented.

Table 4. Distribution of experiments investigated by commodity, continental and agro-climatic region, and the countries and soil orders represented.

Commodity	Continental Region	Countries	Soil Orders	Climatic Regime[a]
				(# of experiments)
Corn	East Africa	Kenya, Malawi, Sudan, Tanzania, Uganda, Zambia, Zimbabwe	Alfisols, Entisols, Mollisols, Oxisols, Vertisols	W/D (17) HT (3)
	West Africa	Burkina Faso, Cameroon, Congo, Ghana, Gambia, Nigeria, Mali, Senegal, Togo	Alfisols, Entisols, Inceptisols, Oxisols, Ultisols	W/D (15) HT (8)
	Carribean	Puerto Rico	Oxisols, Ultisols	Coastal (6) Highlands (6)
	South America	Bolivia, Brazil, Peru	Entisols, Inceptisols, Oxisols, Ultisols	W/D (12) HT (9)
Millet	West Africa	Niger, Nigeria, Mali, Senegal	Alfisols, Aridisols, Inceptisols	W/D (4) Semi-arid (4)
	Asia	India	Alfisols, Aridisols, Inceptisols, Mollisols, Vertisols	W/D (9) Semi-arid (12)
Sorghum	West Africa	Burkina Faso, Cameroon, Nigeria, Mali	Alfisols, Inceptisols	W/D (5)
	Asia	India	Alfisols, Aridisols, Inceptisols, Ultisols, Vertisols	W/D (15) Semi-arid (13)

[a] W/D=wet-dry; HT=humid tropical

Corn

a. *Aboveground N accumulation* - regression slopes in Table 5 show that aboveground N accumulation among the regions and climatic regimes vary from 0.017 to 0.027 kg N/kg of grain yield. Differences in N accumulation are attributed to a combination of factors, namely hybrids and cultivars, harvest indices and N concentrations in both grain and stover. In South America, for example, predicted N accumulation per unit grain yield was similar for all experiments in the ‘Cerrados’ (wet-dry) region, but different from all experiments in the Amazon region (humid tropical). A distinction between experiments in these two regions, in addition to climatic regime, was the use of hybrids in the ‘Cerrados” and improved varieties in the Amazon.

Table 5. Prediction equations for aboveground N accumulation as a function of grain yield, and range or mean values for agronomic properties used in estimating crop N uptake.

			Harvest	N Concentration			
		Country/	Index[b]	Grain		Stover	
Region	**Equation[a]**	**Climate**	**Range**	**Mean**	**Range**	**Mean**	**Range**
				-------------------- $g\ kg^{-1}$	--------------------		
East Africa	Y=9.6+0.024X	Sudan/(W/D)	0.4-0.8	15.8	14.6-19.3	5.9	5.4-7.8
		Zimbabwe/(W/D)	0.5-0.7				
West	Y=5.3+0.017X	Ghana/(W/D)					
Africa	Y=1.4+0.017X	Ghana/(HT)	0.5-0.9	10.6	8.0-12.9	3.0	2.8-3.5
	Y=7.8+0.017X	Nigeria/(W/D)	0.5-1.4	12.0	11.0-13.0	5.4	3.3-6.2
	Y=1.4+0.026X	Nigeria/(HT)	0.3-0.8	14.5	13.5-17.2	11.4	9.2-14.6
		Mali/(W/D)	0.7-0.9				
		Senegal/(W/D)	0.4-0.9				
Puerto Rico	Y=9.2+0.022X	Coastal	0.4-0.5	15.5	13.9-16.5	8.3	6.0-9.8
	Y=9.2+0.027X	Highlands	0.4-0.7	15.8	11.1-17.6	8.9	3.8-13.6
S. America	Y=11.6+0.023X	Brazil/(W/D)	0.7-1.4	13.4	9.0-16.3	5.7	4.1-7.6
		Brazil/(HT uplands)	0.4-0.8	15.6	14.5-16.9	8.2	6.1-12.9
	Y=6.8+0.023X	Brazil/(HT lowlands)	0.5-1.0	16.5	14.4-20.6	6.1	5.1-8.6
		Peru/(HT uplands)	0.7-0.9	16.9		2.3	2.2-2.4

[a] Y=Total aboveground N accumulation in kg ha^{-1}; X=grain yield in kg ha^{-1}

[b] Grain:stover ratio

b. *Yield response to fertilizer N* - yield responses (in % relative yield) to fertilizer N in several regions were similar for experiments conducted in various countries within the same climatic regime (Table 6). Fertilizer N requirements to achieve optimum yields ranged from 36 to 107 kg ha^{-1}, but were not related to the maximum grain yields which ranged from 3.7 to 7.0 t ha^{-1}.

c. *Apparent N recovery and soil N supply* - only a limited number of experiments with corn contained sufficient data to determine apparent fertilizer N recovery (Table 7). Fertilizer N efficiency (Ef), estimated from the slopes of the relations between apparent N recovery and applied N, were similar among experiments and ranged from 41 to 47%. In regions such as Puerto Rico and South America, there was no difference in Ef between climatic regimes; this may be due to distribution of applied N in a greater number of split-applications in high rainfall regions (HT), thus minimizing losses from leaching.

Table 6. Linear-plateau yield response functions, critical fertilizer N levels, and grain yield plateaus, mean and range values for corn in various regions.

Region	Country/Climate	Equation[a]	Critical Fertilizer N	Yield Plateau	Grain Yield Mean	Grain Yield Range
			kg ha^{-1}	%	----- t ha^{-1} -----	
East Africa	Sudan/(W/D)	Y=33+0.79N	81	97	2.6	0.8-5.1
	Kenya-Tanzania/(W/D)	Y=65+0.59N	60	96	3.5	2.1-7.0
	Malawi-Zimbabwe/(W/D)	Y=53+0.74N	51	94	3.5	1.4-7.0
	Zambia/ (W/D)	Y=35+0.61N	107	100	3.1	1.4-6.8
	Uganda (Bukwa)/(H/T)	Y=67+0.91N	36	100	4.3	3.7-5.3
	Uganda (N. Bugisu)/(H/T)	Y=65+0.75N	44	98	4.1	3.0-6.2
West Africa	Burkina Faso, Gambia/(W/D)	Y=45+1.28N	64	93	2.8	1.8-3.8
	Nigeria, Senegal, Mali/(W/D)	Y=33+0.83N	72	92	2.5	0.8-6.4
	Cameroon, Ghana, Nigeria/(HT)	Y=52+0.60N	71	94	3.0	0.7-5.7
	Togo/(HT)	Y=80+0.39N	53	100	3.1	1.6-3.7
Puerto Rico	Coastal	Y=38+0.58N	107	100	3.3	2.2-4.3
	Highlands	Y=70+0.34N	80	97	3.3	1.4-6.4
S. America	Brazil/(W/D)	Y=57+0.50N	72	93	5.0	3.1-6.8
	Brazil-Peru uplands/(HT)	Y=32+0.82N	74	92	3.1	0.8-5.3
	Brazil alluvial/(HT)	Y=57+0.68N	57	96	3.4	2.6-4.3

[a] Y=% of maximum relative yield; N=fertilizer N in kg ha^{-1}

Considerable variation was observed in the means and range of values for soil N supply, both within and across regions, countries and climatic regimes. Estimates of soil N supply can be influenced by previous land-use history; although a general trend towards decreasing soil N supply was observed with successive crop cycles, there were not sufficient crop cycles in the experiments to quantify this time effect.

Table 7. Relations between apparent N recovery (ANR) and fertilizer N, and mean and range of values for soil N supply to corn among experiments in various regions and climatic regimes.

			Soil N Supply	
Region	**Equation**[a]	**Country/Climate**	**Mean**	**Range**
			---------- kg ha^{-1} ----------	
East Africa	ANR=0.44N	Sudan/(W/D)	28	6-49
West Africa	ANR=0.47N	Ghana/(HT)	26	21-33
		Nigeria/(HT)	48	28-89
	ANR=0.51N	Nigeria (W/D)	48	28-89
Puerto Rico	ANR=0.41N	Coastal Plain	47	43-94
		Highlands	71	54-104
S. America	ANR=0.42N	Brazil/(W/D)	65	39-110
		Brazil-upland/(HT)	31	15-45
		Brazil-alluvial/(HT)	55	23-86
		Peru-upland/(HT)	39	33-46

[a] ANR=apparent N recovery in kg ha^{-1}; N=fertilizer N in kg ha^{-1}

d. *Green manure N accumulation and apparent recovery in South America* - investigations of 13 separate experiments in the wet-dry and humid tropical regions that included 17 leguminous species used as green manures indicated that N accumulation in the green manure (Y in kg N ha^{-1}) could be estimated for all species by the equation

$$Y = 7.7 + 0.0222DM$$

where DM = green manure dry matter in kg ha^{-1}. Likewise, apparent recovery of green manure N (ANR) by corn could be estimated by separate expressions for wet-dry and humid tropical climatic regimes:

Wet-dry	ANR = 0.41N
Humid tropical	ANR = 0.08N

where N = accumulated N in the green manure material. The lower N use efficiency factor for green manure in humid tropical regions (8%) as opposed to wet-dry regions (41%) is probably related to higher N losses by leaching and lower maximum corn yields (and, thus, crop N accumulation) in the high rainfall regions.

Millet

a. *Aboveground N accumulation* - experiments conducted in India, Niger and Nigeria contained sufficient data to estimate most of the coefficients. With few exceptions as noted in the tables, however, there were no differences within or among countries between hybrids and improved cultivars. Thus, data for hybrids and cultivars were pooled for many of the coefficient estimates.

Total N accumulation functions represented three distinct groups (Table 8): (i) Niger, North India (New Dehli, Haryana, Hisar, Ludhiana, Jaipur and Agra) and Senegal; (ii) Nigeria and West India (Bombay and Pune); and (iii) East India (Vizianagaram). Harvest indices were noticeably different between hybrids and non-hybrids in North India.

Table 8. Prediction equations for aboveground N accumulation as a function of millet grain yield, and range or mean values for agronomic properties used in estimating crop N uptake.

		Harvest Index[b]	N Concentration			
			Grain		Stover	
Region	**Equation[a]**	**Range**	**Mean**	**Range**	**Mean**	**Range**
			------------------- $g\ kg^{-1}$ -------------------			
Niger/(SA)		0.2-0.5	17.8	13.2-27.6	10.1	4.3-18.0
N. India-hybrid/(SA)	Y=-5.2+0.044X	0.1-1.9	18.4	17.2-19.8	7.3	6.8-7.8
N.India-variety/(SA)		0.1-0.4	18.5	18.4-19.5	5.8	5.6-6.1
Senegal/(SA)						
Nigeria/(SA&WD)	Y=1.8+0.028X					
W. India/(SA)		0.1-0.3	21.5	16.4-22.7	4.5	3.7-6.8
E. India/(SA&WD)	Y=-58.4+0.032X					

[a] Y=Total aboveground N accumulation in $kg\ ha^{-1}$; X=grain yield in $kg\ ha^{-1}$
[b] Grain:stover ratio

b. *Yield response to fertilizer N* - without applied N approximately half of the maximum millet yield was obtained in most regions (Table 9). Data for hybrid and improved varieties were pooled because there was no difference in fertilizer response for any region.

Table 9. Linear-plateau yield response functions, critical fertilizer N levels, and grain yield plateaus, mean and range values for millet in India and West Africa.

Country or Region	**Climate**	**Equation[a]**	**Critical Fertilizer N**	**Yield Plateau**	**Grain Yield Mean**	**Grain Yield Range**
			$kg\ ha^{-1}$	%	----- $t\ ha^{-1}$ -----	
East India	Wet-dry	Y=47+0.62N	83	98	1.6	0.9-2.1
Central India	Semi-arid	Y=55+0.71N	56	94	2.0	1.0-3.6
South India	Wet-dry	Y=55+1.07N	42	100	1.7	0.6-2.4
West India	Semi-arid	Y=52+1.30N	37	100	1.0	0.5-2.2
North India	Semi-arid				1.9	0.8-3.7
NW India	Semi-arid	Y=58+0.60N	58	93	2.7	1.7-3.9
Mali	Semi-arid				1.5	1.1-2.0
Niger	Semi-arid	Y=63+0.69N	47	95	1.3	0.6-2.8
Nigeria	SA & WD	Y=50+0.79N	56	94	2.0	0.9-2.7

[a] Y=% of maximum relative yield; N=fertilizer N in $kg\ ha^{-1}$

c. *Apparent N recovery and soil N supply* - fertilizer N efficiencies (Ef) were in a similar range as for corn, with the exception of the 70% value for the North India data (Table 10). Soil N supply for trials in North India also was considerable higher than for other regions.

Table 10. Relations between apparent N recovery and fertilizer N, and mean and range of values for soil N supply to millet among experiments in Niger, Nigeria and India.

Country or Region	Climate	Equation[a]	Soil N Supply Mean	Soil N Supply Range
			---------- kg ha^{-1} ----------	
North India	Semi-arid	ANR=0.68N	67	47-90
West India	Semi-arid	ANR=0.41N	20	11-34
Niger	Semi-arid	ANR=0.43N	34	19-52
Nigeria	SA & WD	ANR=0.47N	35	31-38

[a] ANR=apparent N recovery in kg ha^{-1}; N=fertilizer N in kg ha^{-1}

Sorghum

a. *Aboveground N accumulation* - experimental data for sorghum came from arid and semi-arid regions in India and West Africa (Burkina Faso, Cameroon, Nigeria and Mali), although the latter trials lacked sufficient data for estimating most of the coefficients. In several instances, prediction equations differed between improved varieties (non-hybrids) and hybrids.

Total N accumulation by sorghum in the Central region of India differed between improved varieties and hybrids (Table 11). The improved varieties had higher N concentrations in the grain than the hybrids.

Table 11. Prediction equations for aboveground N accumulation as a function of sorghum grain yield, and range or mean values for agronomic properties used in estimating crop N uptake.

Region	Equation[a]	Harvest Index[b] Range	N Concentration Grain Mean	N Concentration Grain Range	N Concentration Stover Mean	N Concentration Stover Range
			-------------------- g kg^{-1} --------------------			
N. India/(SA&WD)	Y=18.2+0.025X	0.2-0.7				
C. India-hybrid/(SA&WD)	Y=-2.1+0.019X	0.2-0.8	12.0	9.0-18.0	3.9	3.2-4.3
C. India-variety/(SA&WD)	Y=-2.1+0.079X	0.1-0.6	14.7	13.0-16.6	5.3	3.8-6.0

[a] Y=Total aboveground N accumulation in kg ha^{-1}; X=grain yield in kg ha^{-1}

[b] Grain:stover ratio

b. *Yield response to fertilizer N* - yield response functions to fertilizer N differed between varieties and hybrids for all regions of India, except the South (Table 12). However, there was no consistent difference between varieties and hybrids in terms of fertilizer N requirements for optimum yield.

Table 12. Linear-plateau yield response functions, critical fertilizer N levels, and grain yield plateaus, mean and range values for sorghum in India and West Africa.

Country or Region	**Climate**	**Equation**[a]	**Critical Fertilizer N**	**Yield Plateau**	**Grain Yield Mean**	**Grain Yield Range**
			kg ha^{-1}	%	----- t ha^{-1} -----	
Central India-varieties	SA&WD	Y=58+0.63N	54	92	2.5	0.7-5.1
Central India-hybrids	SA&WD	Y=44+0.60N	89	97	3.7	0.5-5.2
South India	SA&WD	Y=50+0.59N	73	92	3.2	0.7-5.9
West India-hybrids	Wet-dry	Y=52+0.50N	86	96	3.9	3.3-4.5
North India-hybrids	SA&WD	Y=56+0.71N	48	90	2.7	1.1-5.5
North India-varieties	SA&WD	Y=63+0.45N	68	93	2.5	1.0-5.2
Mali	Wet-dry	Y=64+0.33N	100	98	2.7	2.0-3.7
Nigeria	SA & WD	Y=55+0.48N	94	100	1.8	1.2-2.4

[a] Y=% of maximum relative yield; N=fertilizer N in kg ha^{-1}

c. *Apparent N recovery and soil N supply* - data for these estimates were only available for trials in India (Table 13). There was no difference in relations between apparent N recovery and applied N for hybrids in North and Central India, whereas relations for improved varieties differed between the same regions. Fertilizer N efficiency values (Ef) varied considerably between hybrids, varieties and regions within India.

Table 13. Relations between apparent N recovery and fertilizer N, and mean and range of values for soil N supply to sorghum among experiments in North and Central India.

Country or Region	**Climate**	**Equation**[a]	**Soil N Supply Mean**	**Soil N Supply Range**
			---------- kg ha^{-1} ----------	
North&Central India, hybrids	SA & WD	ANR=0.44N	65	43-95
North India, varieties	SA & WD	ANR=0.28N		
Central India, varieties	SA & WD	ANR=0.79N	76	32-135

[a] ANR=apparent N recovery in kg ha^{-1}; N=fertilizer N in kg ha^{-1}

2. *Predicting nitrogen gains from legume N_2-fixation* - (Thomas George, Jonathan Quiton and Paul Singleton) - Despite the substantial contribution BNF can make to the N economy of legumes, there are limited efforts to develop decision aids to better manage legume BNF. Attempts are being made to incorporate a BNF sub-routine to NuMaSS. Several legume crops are included in NuMaSS. The NDSS component of NuMaSS presently predicts N fertilizer requirement for any crop from an algorithm that considers total crop N, total plant available N from soil and manure sources and fertilizer recovery efficiency. Applying the NDSS equation to legumes results in the prediction of N fertilizer required to produce a specified target yield. While the target yield for the legume may be achieved by applying fertilizer N, it would be at a much greater cost and with unnecessarily large wastage of N fertilizer compared to relying on legume's ability to acquire most of its N from BNF. The NDSS module is being programmed to not recommend fertilizer N for legumes, but such a solution misses the opportunity to better manage and benefit from legume BNF. To fully benefit from legume BNF, a subroutine specific to legumes could be incorporated in to the NDSS algorithm. In this paper, we make a preliminary attempt to develop an algorithm to predict potential BNF benefits.

Terminology used:

N_{Demand} = total N that is potentially attainable
$N_{Attained}$ = total N that is actually attained
$N_{Deficit}$ = the deficit in N uptake from soil to meet the potentially attainable total N
$N_{BnfDerived}$ = N derived from biological nitrogen fixation (BNF)
$N_{BnfCapacity}$ = N that could be potentially derived from BNF
$N_{BnfLost}$ = Loss in total N that could have been potentially derived from BNF
$N_{SoilSupply}$ = Mineral N supply in soil
$N_{SoilUptake}$ = Mineral N uptake from soil
$N_{FertSupply}$ = Total fertilizer N supply in soil
$N_{FertUptake}$ = Fertilizer N uptake by plant
$N_{SeedUptake}$ = Seed N assimilated by the plant
mat = period from emergence to maturity
lag =period from emergence to beginning of nitrogen fixation
BNF period = period from end of lag phase to legume maturity
nrf = nitrogen recovery fraction, the fraction of total combined N supply in soil that is recovered by the plant
yrf = yield reduction factor, the reduction in final yield due to a deficit in N uptake during early growth of the legume

The relationships between legume N demand and N supply from combined N sources (soil and fertilizer) and *Rhizobium* symbiosis must be considered in order to predict the N derived from BNF ($N_{BnfDerived}$) by a legume. In a schematic representation of this relationship in a nodulated legume by Marchner (1986), the total N increases asymptotically with increasing combined N supply and the $N_{BnfDerived}$ increases by moderate levels of combined N, but decreases substantially at high levels. George *et al*. (1992) presented a similar scheme wherein there would be a moderate N accumulation by a nodulated legume even at the zero combined N level (Figure 8).

It may be seen from Figure 8 that legume total N ($N_{Attained}$) would be the simplest approximation for $N_{BnfDerived}$ since the *Rhizobium* symbiosis is a N source that supplies N to

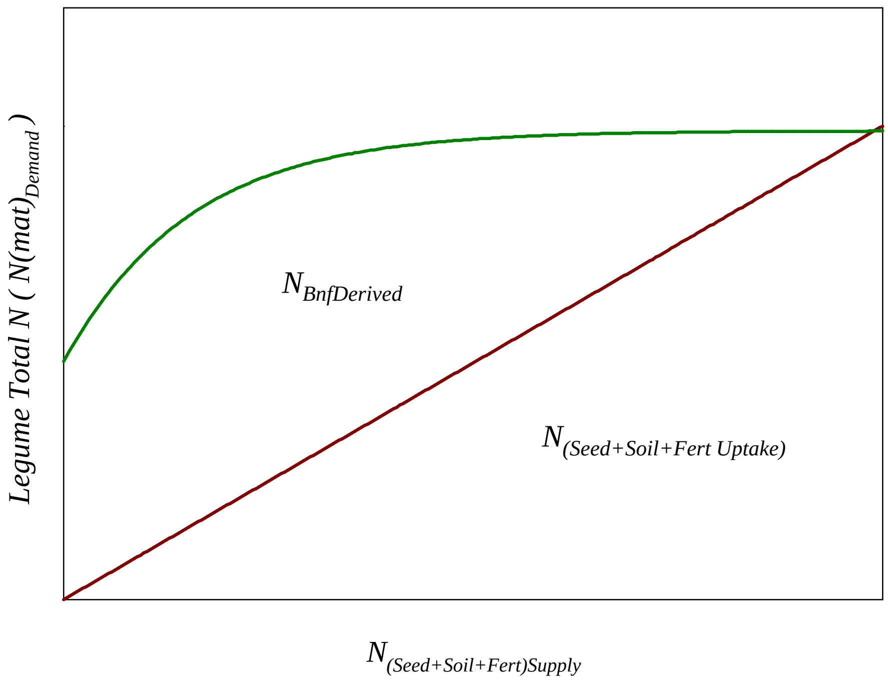

Figure 8. Schematic representation of N demand ($N(mat)_{Demand}$) and N supply to a nodulated legume. Adapted after Marschner, 1986 and George et al., 1992.

the legume in the absence of sufficient combined N. While the symbiosis as an N source may be replaced by a sufficient supply of combined N, it is nearly a non-limiting source with its capacity only limited by the $N_{Attained}$. Therefore, the theoretical upper limit for $N_{BnfDerived,}$ i.e., the potential cumulative BNF capacity at maturity, $N(mat)_{BnfCapacity}$, would be the potential maximum cumulative legume N demand at maturity, $N(mat)_{Demand}$, in a given growing environment. The $N(mat)_{BnfCapacity}$, however, would be somewhat less than the $N(mat)_{Demand}$ due to two reasons. First, the legume-*Rhizobium* symbiosis is not functional during both the initial lag phase of the symbiosis from rhizobial infection to the onset of N_2-fixation and during the late reproductive phase when the nodules senesce (Marschner, 1986). Second, the energy cost of assimilating $N_{BnfDerived}$ is slightly higher than that of combined N (Pate *et al*., 1979; Ryle *et al*., 1979) resulting in lower photosynthate (biomass) accumulation. Thus, the $N_{Attained}$ by plants solely dependent on BNF would always be somewhat lower than that of plants dependent on combined N as observed for several legumes by Thies *et al*. (1991a) and George and Singleton (1992).
Meeting the $N(mat)_{Demand}$ would require a non-limiting supply of combined N, an economically and environmentally undesirable option especially for legumes given the high cost and the low recovery efficiency of N fertilizers. But, combined N supplied during the

early vegetative and late reproductive phases of a BNF-dependent legume can be complimentary in attaining an N yield approximating the maximum possible (George and Singleton, 1992; George *et al*., 1992). In a practical N fertilization scheme, therefore, a well-nodulated legume is more likely to have a higher $N_{Attained}$ compared to one that is not. Thus, $N_{BnfCapacity}$ should increase in tandem with N_{Demand} and should approximate $N(mat)_{Demand}$ expressed as,

$$N(mat)_{BnfCapacity} \cong N(mat)_{Demand} \qquad (2)$$

where $N(mat)_{BnfCapacity}$ is the cumulative BNF capacity from time= 0 to maturity (mat), and $N(mat)_{Demand}$ is the cumulative N Demand from time=0 to maturity.
The lag phase in the legume-*Rhizobium* symbiosis is about 3 to 5 weeks (Marschner, 1986). The dysfunctional symbiosis at late reproductive phase would be about 2 to 3 weeks in an annual legume. Considering N uptake during the late reproductive phase as negligible for most annual legumes and disregarding the reduction in N yield from the higher energy costs, the $N_{BnfCapacity}$ can be expressed as,

$$N(mat)_{BnfCapacity} = N(mat)_{Demand} - N(lag)_{Demand} \qquad (3)$$

where $N(lag)_{Demand}$ is the cumulative N demand from time=0 to the end of the lag phase as depicted in Figure 9.
It can be seen from Figures 8 and 9 that the $N_{BnfCapacity}$ is reduced by the amount of N uptake from any or all of seed ($N_{SeedUptake}$), soil ($N_{SoilUptake}$) and fertilizer ($N_{FertUptake}$) sources. In other words, the $N_{BnfCapacity}$ is in fact the deficit in N demand that is not met by $N_{(Seed+Soil+Fert)Uptake}$ during the period from the onset of N_2 fixation (end of lag phase) to legume maturity, here in after called the BNF period. Thus, the $N_{BnfCapacity}$ would be equal to the aggregate N deficit ($N_{Deficit}$) during the BNF period, which is the difference between the cumulative daily N demand and cumulative daily $N_{(Seed+Soil+Fert)Uptake}$ from lag phase to maturity as described in Equation 4.

$$\begin{aligned} N(mat)_{BnfCapacity} &= \sum_{t=lag}^{mat} \Delta N(t)_{Deficit} \\ &= \sum_{t=lag}^{mat} \left[\Delta N(t)_{Demand} - \Delta N(t)_{(Seed+Soil+Fert)Uptake} \right] \\ &= \sum_{t=lag}^{mat} \Delta N(t)_{Demand} - \sum_{t=lag}^{mat} \Delta N(t)_{(Seed+Soil+Fert)Uptake} \end{aligned} \qquad (4)$$

where D$N(t)_{Deficit}$=daily increment in $N_{Deficit}$ at day=t, D$N(t)_{Demand}$=daily increment in N_{Demand} at day=t, and D$N(t)_{(Seed+Soil+Fert)Uptake}$=daily increment in $N_{(Seed+Soil+Fert)Uptake}$ at day=t.
Given that $N_{SeedUptake}$ precedes the BNF period lasting only until the seed N reserve is utilized, any factor that decreases $N_{(Soil+Fert)Uptake}$ during the BNF period or increases the $N(mat)_{Demand}$ would invariably increase $N_{BnfCapacity}$ (George *et al*. 1988 & 1992, George and Singleton 1992, Thies *et al*. 1991b).

Simplifying Equation 4 yields:

$$N(mat)_{BnfCapacity} = \left[N(mat)_{Demand} - N(lag)_{Demand}\right] - \left[N(mat)_{(Seed+Soil+Fert)Uptake} - N(lag)_{(Seed+Soil+Fert)Uptake}\right] \quad (5)$$

When $N(lag)_{(Seed+Soil)Uptake}$ is inadequate to meet the $N(lag)_{Demand}$, the alleviation of N stress with supplementary fertilizer N increases the $N_{BnfDerived,}$ in a phenomenon often referred to as the `starter N' effect (Marschner, 1986; George *et al*. 1992). In other words, when there is a $N(lag)_{Deficit}$, i.e., $N(lag)_{(Seed+Soil)Uptake} < N(lag)_{Demand}$, the $N(mat)_{BnfDerived}$ is reduced because of a reduction in $N(mat)_{Demand}$. Meeting the $N(lag)_{Deficit}$ by starter N fertilizer ensures that $N(mat)_{Demand}$ is at its maximum and therefore, $N(mat)_{BnfDerived}$ is also at its maximum. Therefore, if the reducing effect of $N(lag)_{Deficit}$ on $N(mat)_{Demand}$ can be predicted, the consequent loss in $N(mat)_{BnfDerived}$ can also be estimated.

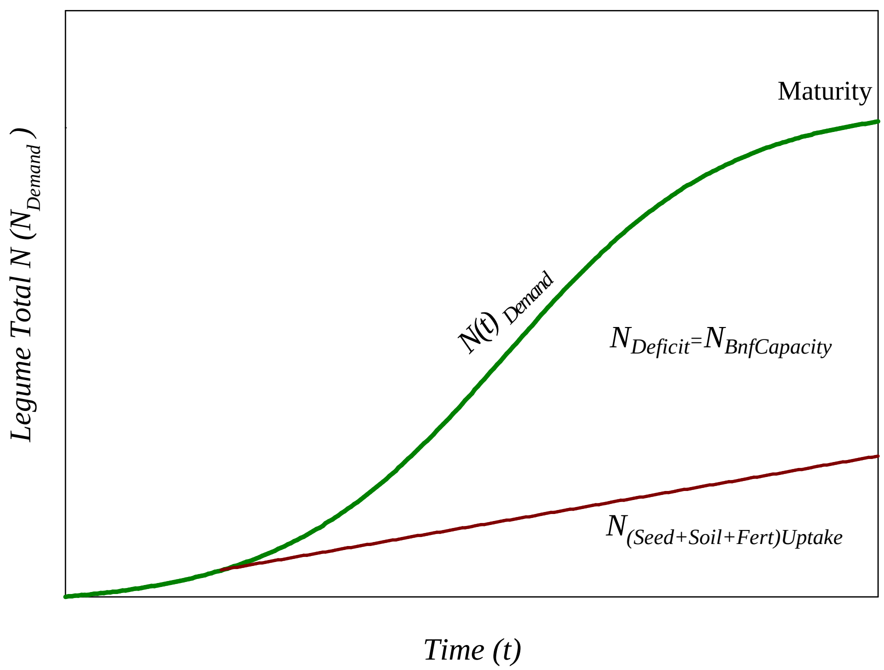

Figure 9. Conceptual time course of legume N demand indicating BNF capacity as the remainder of N uptake from seed, soil and fertilizer N. Adapted from George et al., 1992.

By establishing the time course curves for cumulative N_{Demand} and $N_{(Seed+Soil)Uptake}$, $N_{Deficit}$ at any time point can be determined. From data on soybean from humid tropics (George and Singleton, 1992; George unpublished), it was found that the cumulative N demand followed a modified logisitic equation as follows (Figure 10).

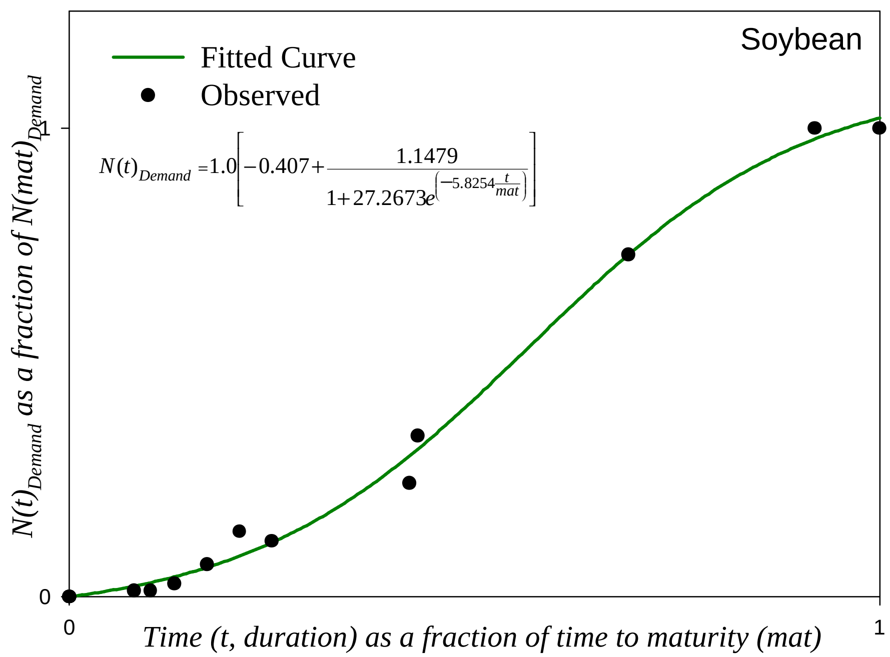

Figure 10. Cumulative N demand during the growth cycle of soybean in the humid tropics (data from George and Singleton, 1992 and George, unpublished).

$$N(t)_{Demand} = K \cdot \left[a + \frac{b}{1 + c \cdot e^{\left(d \frac{t}{mat}\right)}} \right] \tag{6}$$

where K = N carrying capacity of the legume crop and a, b, c, and d are parameters specific to the crop controlling the shape of the curve based on flowering date and total crop duration.

The cumulative $N_{SoilUptake,}$ on the other hand, found to follow a linear response for the growth period excluding the early seedling phase when the plant is dependent only on $N_{SeedUptake}$ and the late maturity phase when the plant is no longer absorbing soil N. Assuming that $N_{SoilUptake}$

is negligible for about 7 days each after seeding and before maturity, the $N_{SoilUptake}$ can be expressed as,

$$N(t)_{SoilUptake} = \begin{cases} N_{Seed} & , \quad t \leq 7 \\ N_{Seed} + (t-7)\dfrac{N(mat)_{SoilUptake} - N_{Seed}}{mat-14} & , \quad 7 < t \leq (mat - 7) \\ N(mat)_{SoilUptake} & , \quad t > (mat - 7) \end{cases} \tag{7}$$

By determining the $N(lag)_{Demand}$ and $N(lag)_{(Seed+Soil)Uptake}$, the $N(lag)_{Deficit}$ can be calculated as follows,

$$N(t)_{Deficit} = N(t)_{Demand} - \left[N(t)_{(Seed+Soil+Fert)Uptake} + N(t)_{BnfDerived}\right] \tag{8}$$

In order to predict the reducing effect of $N(lag)_{Deficit}$ on $N(mat)_{Attained}$, an yield reduction fraction (*yrf*) must be first determined based on a relationship between expected incremental increases in $N(mat)_{Demand}$ from unit increases in $N(lag)_{(Seed+Soil+Fert)Uptake}$. It was found that the relationship between $N(mat)_{Attained}$ as a fraction of $N(mat)_{Demand}$ and $N(lag)_{Attained}$ as a fraction of $N(lag)_{Demand}$ followed a quadratic response for soybean in the tropics based on data from George and Singleton (1992) (Figure 11) as represented in the generic equation 9.

$$yrf(t_2 \mid t_1) = a\left[\frac{N(t_1)_{Attained} - N_{SeedUptake}}{N(t_1)_{Demand} - N_{SeedUptake}}\right]^2 + b\left[\frac{N(t_1)_{Attained} - N_{SeedUptake}}{N(t_1)_{Demand} - N_{SeedUptake}}\right] + \frac{N^*(t_2)_{Attained}}{N(t_2)_{Demand}} \tag{9}$$

where $yrf(t_2|t_1)$= yield reduction fraction at time= t_2 given $N_{Attained}$ at time= t_1 (where $t_0 < t_1 < t_2$); t_0=0 (i.e, at seeding); t_1=any time from 0 to mat; t_2=any time from t_1 to mat; a=quadratic coefficient; b=linear coefficient; and $N^*(t_2)_{Attained}$ = minimum N attained at t_2 when N_{Uptake} is only $N_{SeedUptake}$ + $N_{BnfDerived}$ (the latter applicable only to legumes).

The *yrf* would be crop, time and environment specific as its value is determined by the extent of N_{Demand} at time t_2 that is potentially attainable at a given $N_{Attained}$ or $N_{Deficit}$ at a preceding time t_1. For nodulated soybean in the tropics, $N^*(mat)_{Attained}$ is assumed to be 25% of $N(mat)_{Demand}$. With the *yrf*, the $N(mat)_{Attained}$ can be calculated as follows,

$$N(mat)_{Attained} = yrf(mat \mid lag) \cdot N(mat)_{Demand} \tag{10}$$

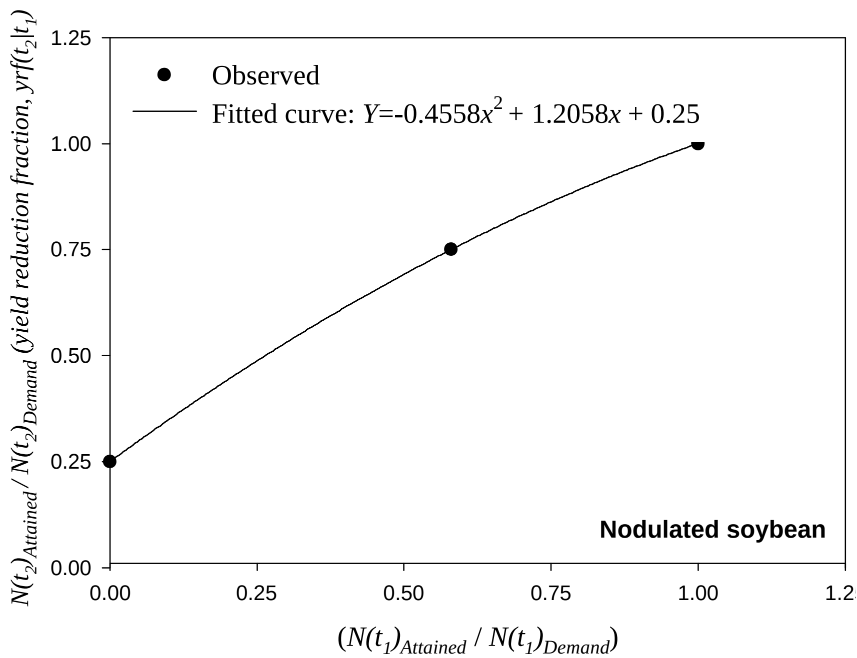

Figure 11. The relationship between N attained at time t_2 and time t_1 by nodulated soybean. The $(N(t_2)_{Attained}/N(t_2)_{Demand})$ is expressed as a yield reduction fraction ($yrf(t_2/t_1)$). For nodulated soybean, the minimum N attained when N from seed is the only source of N_{uptake} is assumed to be 0.25. Data from George and Singleton, 1992.

In terms of actual $N_{BnfDerived}$ and $N_{Attained}$, equation 5 can be rewritten as,

$$\begin{aligned} N(mat)_{BnfDerived} = &\left[N(mat)_{Attained} - N(lag)_{Attained}\right] \\ &-\left[N(mat)_{(Seed+Soil+Fert)Uptake} - N(lag)_{(Seed+Soil+Fert)Uptake}\right] \end{aligned} \quad (11)$$

Since, $N(lag)_{Attained}$ would equal $N(lag)_{(Seed+Soil+Fert)Uptake}$, equation 11 simplifies to,

$$N(mat)_{BnfDerived} = N(mat)_{Attained} - N(mat)_{(Seed+Soil+Fert)Uptake} \quad (12)$$

When $yrf(mat|lag)$ = 1 (i.e., no yield reduction), $N(mat)_{Attained}$ would equal $N(mat)_{Demand}$ and $N(mat)_{BnfDerived}$ would equal $N(mat)_{BnfCapacity}$. Therefore, when $yrf(mat|lag)$ is less than 1, there would be a loss in $N(mat)_{BnfDerived}$. Thus,

$$N(mat)_{BnfLost} = N(mat)_{Demand} - N(mat)_{Attained} \quad (13)$$

where $N_{BnfLost}$ is the cumulative potential loss in BNF if $N(lag)_{Deficit}$ is not eliminated by the application of starter N fertilizer.

Maximizing the $N_{BnfDerived}$ would require managing the starter N effect without a drawn out effect of applied fertilizer N replacing subsequent $N_{BnfDerived}$. Therfore, it is important that the right amount of starter N fertilizer is applied.

The amount of N fertilizer that must be applied to any crop to meet a given N demand depends on a nitrogen recovery fraction (*nrf*), which is the fraction of total combined N supply in soil ($N_{(Soil+Fert)Supply}$) that is recovered by the crop ($N_{(Soil+Fert)Uptake}$). Thus,

$$N(mat)_{(Soil+Fert)Uptake} = nrf(mat) \cdot N(mat)_{(Soil+Fert)Supply} \qquad (14)$$

It should be noted that the $N_{SoilSupply}$ is likely to be relatively constant for a given soil and season unlike $N_{FertSupply}$ which is dependent on the timing and amount of application. But regardless of N supply, George and Singleton (1992) found that legume species do differ in their *nrf* (George and Singleton, 1992). Thus, under same $N_{(Soil+Fert)Supply}$, legumes that are efficient in extracting soil N will have a greater $N(t)_{(Soil+Fert)Uptake}$, a lower $N(t)_{Deficit}$, and consequently a lower $N(t)_{BnfDerived}$, than those that are not. Using ^{15}N, George and Singleton (1992) determined in the field that common bean scavenges N from soil much more efficiently than soybean, partly contributing to its lower $N(mat)_{BnfDerived}$ compared to soybean. The *NRF* of soybean was less than half that of common bean and, consequently, KCl-extracted mineral N in the soil under soybean was almost twice as high as that under common bean. Further, the data indicated that the *nrf* as determined by ^{15}N increases with time as indicated by the increasing linear coefficients for plots of $N_{FertSupply}$ vs. $N_{FertUptake}$ for periods of 35 days, 58 days and 84 days for soybean (Figure 12).

Rewriting, equation 12 will yield,

$$N(mat)_{BnfDerived} = N(mat)_{Attained} - \left[N_{SeedUptake} + nrf(mat) \cdot N(mat)_{(Soil+Fert)Supply}\right] \qquad (15)$$

As pointed out earlier, $N(mat)_{BnfDerived}$ would be the maximum when $N(lag)_{Deficit}$ is eliminated by starter N fertilizer. To meet the $N(lag)_{Deficit}$, therefore, the amount of starter N fertilizer required could be calculated as,

$$\text{Starter N fertilizer} = \frac{N(lag)_{Deficit}}{nrf(lag)} \qquad (16)$$

Any increase in $N_{BnfDerived}$ from the starter N effect is further influenced by the pattern of N assimilation (George and Singleton, 1992). A legume that is able to meet its $N(lag)_{Demand}$ from $N(lag)_{(Seed+Soil)Supply}$ (no $N(lag)_{Deficit}$), but has subsequent N requirement that substantially exceeds $N(mat)_{(Seed+Soil)Uptake}$ would have high $N(mat)_{BnfDerived}$ because of high $N_{Deficit}$ during the BNF period. Consequently, in contrast to common bean, soybean that has a high N requirement from flowering to mid-podfill also has high BNF rates during the same period (George and Singleton 1992). Thus, the $N(mat)_{BnfLost}$ would be much larger for a legume such as soybean if the $N(lag)_{Deficit}$, which although is much smaller compared to common bean, is not met.

Summary - We were able to develop a preliminary model to predict N derived from BNF by legumes for possible improvement of the NDSS module of NuMaSS. Our concepts and model are based on limited data available particularly on N accumulation and biological N fixation during in early growth of a legume. The terminology and computations used in this paper are preliminary in nature. Next step would be to improve on the terminology and computations and test and improve the model with additional data from core as well as other experiments.

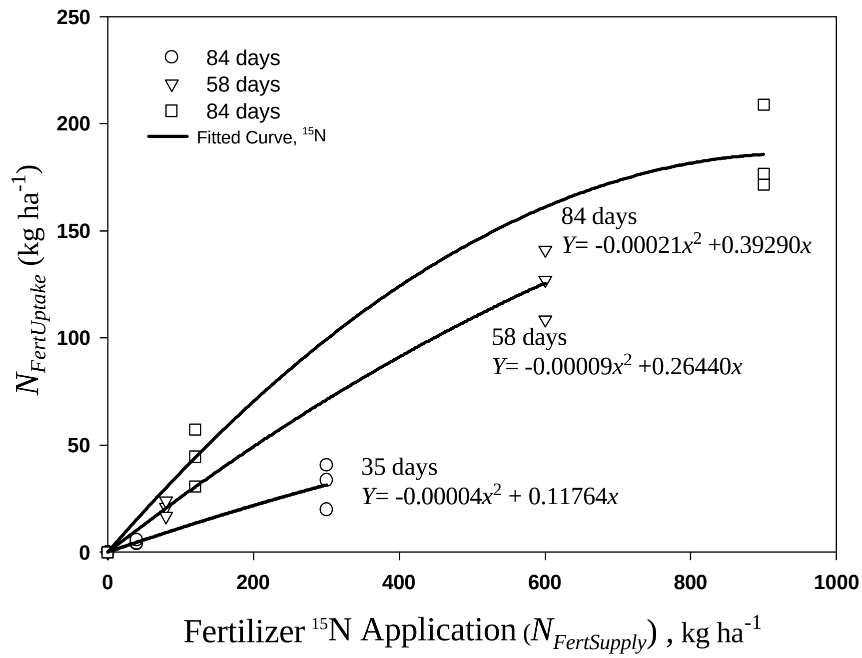

Figure 12. Relationship between fertilizer nitrogen uptake ($N_{FertUptake}$) and fertilizer nitrogen supply ($N_{FertSupply}$) in soybean estimated using ^{15}N (Adapted from George and Singleton, 1992).

Literature Cited -

George T., J. K. Ladha, R. J. Buresh, and D. P. Garrity. 1992. Managing native and legume-fixed nitrogen in lowland rice-based cropping systems. Plant Soil 141:69-91.

George, T. and P.W. Singleton. 1992. Nitrogen assimilation traits and dinitrogen fixation in soybean and common bean. Agron. J. 84:1020-1028.

Marschner, H. 1986. Mineral nutrition of higher plants. Academic Press. San Diego, CA.

External Funding and Support

IRRI: Travel and time costs $5, 000

Collaborators at intensive sites are conducting laboratory, greenhouse and field trials on various aspects of soil acidity management. Estimates of their funding contributions to this output are contained in values provided for Objective 1, Output 2.

Travel and Meetings Attended

Pedro Luna attended the ASA/CSA/SSSA Annual Meetings to present a poster describing the development of N coefficients for NuMaSS.

Relevant Publications, Reports and Presentations at Meetings

Luna-Orea, P, D.L. Osmond, T.J. Smyth, M.G. Wagger and D.W. Israel. 2000. Methodology to generate NDSS-NuMaSS parameters and calculate N requirements: the case for maize in South America. Agron. Abstr. p.60.

Output 3 Enhancing the knowledge base for the phosphorus decision support system - collecting, developing and synthesizing soil, plant and management information to improve the diagnosis and recommendations of location-specific P problems.

The P module in NuMaSS is at a younger stage of development than the modules for acidity and N. For many conditions, predicted P requirements are uncertain or undetermined; existing coefficients need to be improved and expanded over more soil and crop conditions; our current ability to diagnose and prescribe P requirements for tree species is limited. Rock phosphate exists in local deposits and, when of high quality and applied to acid soils or perennial crops, it can be as effective as soluble fertilizer P. To enable users to consider rock P options algorithms are needed that predict their performance based on data and information available to the intended users.

Milestone events for this output, during the 5-year plan are as follows:

- Development of P diagnosis, prediction and fertilizer guidance for tree crops - beginning in year 1 and completed in year 3;
- Refinement of soil P coefficients for improved P predictions - beginning in year 2 and completed in year 3;
- Predicting effects of P fertilizer placement - year 3; and
- Prediction and fertilizer guidance for rock P use - beginning in year 4 and completed in year 5.

Lead Investigators and Contributors

Russell Yost provides overall coordination to activities related to the P module. During the past year Yost received funding to continue P activities related to tree crops and predicting placement effects of fertilizer P. Cox continues to work on testing short-term methods for estimating P buffer coefficients using residual funds from years 1 and 2. Hossner continues testing diagnostic methods and P recommendations in on-station and on-farm trials in Mali. All U.S. members of the P group and testing site collaborators continued to share via correspondence their findings upon searches of the existing literature. Yost, Cox and Hossner are also contributing on P-related issues of the core experiments at the three intensive testing sites. Collaborators contributing to this output during year 2 are listed according to their respective institutions:

University of Hawaii - X. Wang, X. Shuai, Adrian Ares, and Richard Kablan.

University of Costa Rica - Alfredo Alvarado, Rafael Salas, Eloy Molina, Lidieth Uribe, Gabriela Soto and Jimmy Boniche.

Costa Rica Ministry of Agriculture, 'Los Diamantes' Experiment Station - Antonio Bogantes

Amazonia National Research Institute/Brazil - Charles Clement, Newton Falcão, Kukio Yuyama.

University of the South, Sewanee, TN - Deborah MacGrath

Institute d'Economie Rurale/Mali - Mamadou Doumbia, Aminata Sidibe, M. Keita, O.B. Coumare.

ICRISAT/Niger - A. Bationo

International Rice Research Institute - Thomas George and J. Quiton.

Philippines Rice Research Institute - Teodula Corton, Josephina Lasquite

Ilagan Research Station - Quirino Ascuncion and Danilo Tumamao.

EMBRAPA/Manaus - Manoel Cravo and Jeferson Macedo.

Progress

1. *Greenhouse P fertilization trial with peach palm seedlings* - (supervised by Eloy Molina, Alfredo Alvarado and Jimmy Boniche, with support from Fred Cox) the purpose of this experiment is to evaluate P uptake and growth response by peach palm seedlings from Ultisols and Andisols in Costa Rica. In September, 2000 a greenhouse experiment was initiated in the La Leona area near Guapiles, Costa Rica to determine P uptake by palmito seedling from 10 soils, 5 Andisols and 5 Ultisols. It had taken considerable time to select and collect these soils from the region as they had to be low in P and represent the change in soil characteristics from Andisol to Ultisol. Six rates of P were applied to each soil based on a short-term P sorption assessment. The Los Diamantes Experiment Station provided palmito seedlings which were transplanted to each pot. There was considerable variablity among the seedlings, so after planting the height of each was measured. After about 4 months, plant height will again be measured and soil and plant (a few leaflets) samples taken and P determined. After several more months, the same measurements plus plant weight will be taken and the data analyzed to determine P sorption by the soil and the ability of the plant to take up P from soils varying in characteristics from Andisols to Ultisols. This will assist in confirming the soil properties, especially of the Andisols, that should be considered in evaluating soil P and recommending P fertilization in the Decision Support System.
2. *Laboratory P incubations as estimates of soil P buffer coefficients* - (supervised by Eloy Molina and Alfredo Alvarado, with support from Fred Cox) the purpose of this study is to determine factors affecting P sorption in a variety of soils, primarily Andisols and Ultisols, as part of our effort to devise laboratory methods to estimate field P buffer coefficients for NuMaSS.The Soils Laboratory at the University of Costa Rica analyzed selected chemical and physical properties of 62 soils. After several reruns were conducted, these data were used to determine the relationship between P sorption and soil properties for soils which vary in clay type from crystalline to non-crystalline for use in PDSS. Countries of origin and number of soils were Costa Rica 45, Ecuador 8, Panama 3, Hawaii 3, Honduras 2, and Guatemala 1 (Table 14). Data included nutrients extracted by Modified Olsen and Mehlich 3, pH, organic matter, acidity, texture, amorphous Fe, amorphous Al (AmAl), and KOH-extractable Al (KOHAl).

   The soils were also mixed with 0, 35, 70, and 140 ug P/cm^3, allowed to dry, and extracted with both Modified Olsen and Mehlich 3 to determine the change (recovery) in soil test P per unit of P applied. Soil test P generally increased linearly with rate of P applied (Table 15). The slopes determined from these relationships were termed the Modified Olsen (MOPBC) and Mehlich 3 (M3PBC) P buffer coefficients. These slopes were markedly greater for soils with high initial soil test P, so soils with P greater than 20 ug/cm^3 in the check samples by either method or in the original samples by the Modified Olsen were deleted from further evaluation. Soils with high soil test P do not require diagnosis and interpretation by PDSS anyway. Thus, data from 21 soils were deleted, leaving a set of 41 with 18 Andisols, 21 Ultisols, and 2 Oxisols.

Table 14. General chemical and physical soil data from the analyses conducted in Costa Rica.

Soil			Amorphous		KOH		Exchangeable					Org.			
No.	Order	Country	Al	Fe	Al	pH	Ca	Mg	K	Acid.	CEC	Mat.	Sand	Silt	Clay
			----------- % -----------				--------------- cmol dm^{-3} ---------------					--------------- % ---------------			
1	Ultisol	Costa Rica	1.65	0.54	0.33	5.0	4.54	1.41	0.23	1.20	7.38	7.71	48	17	35
3	Ultisol	Costa Rica	0.64	0.32	0.19	4.6	3.50	1.96	0.81	4.40	10.67	8.71	39	32	29
4	Ultisol	Costa Rica	0.71	1.24	0.36	4.9	1.17	0.36	0.10	1.80	3.43	3.89	28	19	53
5	Ultisol	Costa Rica	0.81	1.04	0.44	5.2	3.25	1.71	0.14	5.20	10.30	4.02	29	18	53
6	Ultisol	Costa Rica	2.88	0.3	0.48	5.2	1.08	0.16	0.08	0.60	1.92	1.94	29	26	45
7	Ultisol	Costa Rica	2.16	1.12	0.78	5.3	3.40	1.17	0.32	0.50	5.39	6.43	14	26	60
8	Ultisol	Costa Rica	2.66	0.83	0.81	5.5	0.72	0.36	0.18	0.70	1.96	7.89	44	23	33
9	Ultisol	Costa Rica	1.75	0.71	0.66	5.1	1.70	0.17	0.16	0.70	2.73	5.25	45	14	41
10	Ultisol	Costa Rica	3.20	0.54	0.72	5.1	1.60	0.20	0.05	0.70	2.55	4.29	29	16	55
11	Ultisol	Costa Rica	1.20	0.49	0.47	4.3	1.60	0.99	0.17	5.40	8.16	8.91	14	26	60
12	Ultisol	Costa Rica	0.57	1.55	0.37	5.4	5.12	2.27	0.23	0.90	8.52	3.22	34	15	51
13	Ultisol	Costa Rica	1.18	1.55	0.51	4.9	1.24	0.35	0.48	2.80	4.87	7.17	31	23	46
14	Ultisol	Costa Rica	1.48	1.55	0.44	5.3	0.84	0.33	0.12	1.40	2.69	3.95	29	21	50
15	Ultisol	Costa Rica	0.12	0.49	0.8	5.5	15.40	6.30	0.14	0.80	22.91	3.55	34	34	32
16	Ultisol	Costa Rica	4.49	1.11	0.19	5.6	2.92	0.70	0.10	0.90	4.62	9.31	19	34	47
17	Ultisol	Costa Rica	2.95	0.45	0.32	5.0	2.27	0.40	0.39	2.20	5.26	2.95	6	16	78
18	Ultisol	Costa Rica	0.94	1.93	0.39	4.8	1.29	0.52	0.53	1.80	4.14	5.43	46	32	22

Soil			Amorphous		KOH		Exchangeable					Org.			
No.	Order	Country	Al	Fe	Al	pH	Ca	Mg	K	Acid.	CEC	Mat.	Sand	Silt	Clay
			----------- % -----------				--------------- cmol dm^{-3} ---------------					--------------- % ---------------			
19	Ultisol	Costa Rica	3.38	0.92	0.66	4.8	1.53	0.48	0.18	1.00	3.19	6.36	35	26	39
20	Ultisol	Costa Rica	0.62	1.07	0.42	5.3	6.03	1.80	0.15	1.50	9.48	7.44	28	17	55
22	Ultisol	Costa Rica	0.96	2.07	0.56	5.1	7.04	3.14	0.37	6.30	16.85	4.96	28	22	50
24	Ultisol	Costa Rica	0.52	0.68	0.31	5.3	6.25	1.81	0.09	0.60	8.75	3.48	49	11	40
76	Andisol	Costa Rica	2.83	1.86	1.27	6.0	3.79	1.36	0.45	0.50	6.10	8.20	64	31	5
77	Andisol	Costa Rica	3.67	2.59	2.42	5.5	0.63	0.27	0.29	0.40	1.59	24.00	73	19	8
78	Andisol	Costa Rica	2.25	2.64	1.02	5.8	5.71	1.67	0.44	0.40	8.22	10.80	56	30	14
79	Andisol	Costa Rica	5.10	2.12	3.41	5.9	1.73	0.40	0.13	0.70	2.96	13.30	68	30	2
80	Andisol	Costa Rica	4.05	1.19	2.71	6.0	10.10	2.10	0.72	0.30	13.22	20.40	60	25	15
81	Andisol	Costa Rica	0.95	1.39	0.54	6.3	11.10	2.17	2.05	0.30	15.62	5.20	46	22	32
82	Andisol	Costa Rica	4.72	1.05	2.81	6.0	7.17	0.75	0.31	0.40	8.63	13.90	50	34	16
83	Andisol	Costa Rica	1.12	1.16	0.47	5.9	4.98	1.32	1.00	0.40	7.70	4.76	12	30	58
84	Andisol	Costa Rica	0.92	0.71	0.32	5.5	3.64	1.57	0.49	0.40	6.10	5.01	78	20	2
85	Andisol	Costa Rica	2.25	0.75	0.85	6.0	5.20	0.47	0.40	0.30	6.37	5.65	60	27	13
86	Andisol	Costa Rica	5.07	1.92	5.07	6.3	4.80	0.68	0.80	0.20	6.48	10.60	63	29	8
87	Andisol	Costa Rica	4.82	1.55	2.71	5.4	0.73	0.32	0.35	1.20	2.60	18.80	71	19	10
88	Andisol	Costa Rica	4.75	1.34	2.57	5.8	1.25	0.23	0.30	0.40	2.18	22.50	81	14	5
89	Andisol	Costa Rica	0.72	1.29	0.30	5.9	10.50	3.23	0.87	0.50	15.10	6.55	71	24	5

Soil			Amorphous		KOH		Exchangeable					Org.			
No.	Order	Country	Al	Fe	Al	pH	Ca	Mg	K	Acid.	CEC	Mat.	Sand	Silt	Clay
			----------- % -----------				--------------- cmol dm^{-3} ---------------					--------------- % ---------------			
90	Andisol	Costa Rica	1.87	0.79	0.88	6.3	8.87	0.78	0.29	0.20	10.14	7.57	45	49	6
92	Andisol	Costa Rica	1.77	1.10	0.59	4.6	3.88	1.35	2.50	0.90	8.63	7.11	70	10	20
93	Andisol	Costa Rica	2.87	0.92	2.21	5.8	7.59	2.50	0.66	0.30	11.05	8.84	60	30	10
94	Andisol	Costa Rica	2.47	0.73	0.94	5.7	3.94	1.35	1.22	0.20	6.71	14.10	55	41	4
95	Andisol	Costa Rica	4.15	0.54	2.79	5.8	4.12	0.94	0.23	0.20	5.49	5.32	70	23	7
96	Andisol	Costa Rica	3.97	0.55	2.79	5.8	3.34	0.56	0.21	0.20	4.31	12.19	60	26	14
97	Andisol	Costa Rica	4.35	1.39	3.38	5.7	2.93	0.24	0.18	0.20	3.55	12.05	52	42	6
98	Andisol	Costa Rica	4.55	0.95	3.07	5.4	2.40	0.30	0.22	0.30	3.22	9.23	60	28	12
99	Andisol	Costa Rica	0.25	1.29	0.22	6.2	29.70	6.60	1.01	0.20	37.51	4.09	36	37	27
100	Andisol	Costa Rica	2.67	1.50	0.79	4.8	3.05	1.36	0.24	7.60	12.25	8.44	55	34	11
101	Andisol	Ecuador	0.65	0.47	0.30	5.6	6.63	1.31	0.19	0.30	8.43	6.37	51	41	8
102	Andisol	Ecuador	0.50	0.41	0.25	5.6	9.63	1.76	0.19	0.35	11.93	7.29	45	46	9
103	Andisol	Ecuador	0.40	0.41	0.28	6.0	8.50	1.80	0.59	0.25	11.14	8.23	45	43	11
104	Andisol	Ecuador	0.55	0.46	0.32	6.3	6.60	1.89	0.41	0.20	9.10	5.64	61	30	9
105	Andisol	Ecuador	0.30	0.75	0.26	5.5	8.00	2.60	0.20	0.25	11.05	5.97	69	25	6
106	Andisol	Honduras	1.52	1.11	0.83	6.7	2.74	0.50	0.34	0.80	4.38	5.57	16	29	55
107	Andic	Honduras	0.95	1.02	0.98	6.2	9.16	3.44	0.52	0.20	13.32	4.38	62	24	14
108	Ultisol	Panama	0.92	0.29	0.26	5.4	1.55	0.36	0.10	1.65	3.66	4.64	23	22	55

Soil			Amorphous		KOH		Exchangeable					Org.			
No.	Order	Country	Al	Fe	Al	pH	Ca	Mg	K	Acid.	CEC	Mat.	Sand	Silt	Clay
			----------- % -----------				--------------- cmol dm^{-3} ---------------					--------------- % ---------------			
109	Oxisol	Hawai	1.60	0.44	0.33	5.0	1.76	1.35	0.39	0.35	3.85	5.17	18	15	68
110	Oxisol	Hawai	1.67	0.89	0.68	5.0	2.40	0.78	0.15	0.40	3.73	7.10	74	16	11
111	Andisol	Hawai	4.55	7.64	3.45	5.2	3.98	0.72	0.18	0.95	5.83	6.51	53	31	16
112	Andisol	Panama	3.45	1.09	2.37	5.2	2.16	0.42	0.40	0.60	3.58	10.54	47	32	21
113	Andisol	Panama	3.62	1.03	2.51	5.5	1.65	0.31	0.30	0.60	2.86	8.29	42	40	18
114	Andisol	Ecuador	1.22	0.93	0.99	5.5	8.52	0.58	0.35	0.25	9.70	4.97	32	43	25
115	Andisol	Ecuador	1.10	0.90	0.87	5.7	8.28	0.62	0.44	0.25	9.59	5.11	36	44	20
116	Andisol	Ecuador	1.27	0.97	1.02	6.7	8.83	0.58	0.32	0.20	9.93	5.24	30	45	25
117	Andisol	Guatemala	2.75	0.88	2.19	7.0	8.53	1.64	0.42	0.20	10.79	10.15	48	35	18

Table 15. Modified Olsen and Mehlich 3 P after application of four rates of P to the soils from Costa Rica.

Soil	Modified Olsen Extractant					Mehlich 3 Extractant				
	Applied P (mg dm^{-3})				Buffer	Applied P (mg dm^{-3})				Buffer
ID	0	35	70	140	Coeff.	0	35	70	140	Coeff.
	----- P recovery, mg dm^{-3} -----					----- P recovery, mg dm^{-3} -----				
1	6.8	8.0	10.6	19.8	0.096	5.2	6.8	10.3	18.0	0.094
3	12.9	25.4	32.4	41.0	0.192	5.4	12.7	20.6	41.3	0.258
4	5.0	9.5	19.1	40.2	0.259	4.6	8.2	15.9	29.4	0.183
5	4.2	5.3	10.3	21.5	0.129	6.1	8.5	13.7	26.4	0.149
6	3.2	3.5	6.0	16.0	0.096	5.2	5.3	6.7	10.3	0.038
7	7.3	8.0	13.7	23.3	0.121	7.0	11.0	14.6	23.2	0.115
8	5.6	10.5	18.6	35.5	0.218	4.8	11.6	18.0	23.6	0.132
9	4.2	5.3	11.1	27.6	0.175	4.5	7.0	12.1	18.8	0.105
10	5.2	5.4	9.5	22.2	0.128	2.8	5.8	12.4	17.9	0.112
11*	21.9	40.2	45.6	61.0	0.262	131.0	137.0	149.0	188.0	0.415
12	1.4	4.3	8.7	21.5	0.147	5.2	7.7	11.6	22.1	0.123
13	5.7	9.3	14.2	31.0	0.184	5.3	15.4	20.7	33.4	0.194
14	1.5	5.2	8.4	20.5	0.136	5.6	9.3	14.9	25.1	0.142
15	3.4	9.8	17.0	37.4	0.245	5.8	21.7	29.1	48.2	0.292
16	1.5	6.3	10.5	13.8	0.086	6.2	11.3	15.0	22.7	0.116
17	3.9	5.3	8.3	13.7	0.072	6.3	10.3	13.6	19.1	0.090
18	5.6	11.4	16.2	27.9	0.158	11.2	18.7	26.8	42.4	0.223
19	4.0	7.9	13.3	27.1	0.168	3.4	13.7	21.3	37.0	0.236
20	3.8	10.4	16.6	29.0	0.179	6.0	13.7	21.5	43.2	0.267
22	4.7	9.5	16.5	33.2	0.207	7.5	16.1	20.3	36.7	0.204
24	2.9	4.4	7.2	11.4	0.066	1.8	4.0	8.5	19.1	0.127
76	6.4	16.8	21.1	32.5	0.178	16.0	19.9	30.8	37.6	0.161
77	6.2	20.6	25.3	35.1	0.193	6.6	17.0	20.2	30.8	0.163
78	2.2	11.3	15.7	26.9	0.170	4.6	7.3	11.5	18.9	0.104
79	2.4	8.1	10.3	17.2	0.101	5.6	6.8	7.8	9.8	0.030

	Modified Olsen Extractant					Mehlich 3 Extractant				
Soil	Applied P (mg dm^{-3})				Buffer	Applied P (mg dm^{-3})				Buffer
ID	0	35	70	140	Coeff.	0	35	70	140	Coeff.
	----- P recovery, mg dm^{-3} -----					----- P recovery, mg dm^{-3} -----				
80*	35.5	90.0	97.0	75.5	0.211	54.0	74.0	81.0	103.0	0.333
81*	39.5	89.5	106.0	101.0	0.383	57.0	63.5	75.5	94.5	0.275
82	5.0	12.1	14.9	20.6	0.105	6.1	7.3	8.4	9.5	0.024
83*	33.0	33.0	33.0	37.0	0.029	107.0	113.0	146.0	199.0	0.690
84*	54.1	170.0	232.0	234.0	1.180	200.0	200.0	223.0	264.0	0.485
85*	76.2	78.0	92.5	122.0	0.342	121.0	127.0	142.0	167.0	0.338
86	2.3	2.3	4.3	9.3	0.053	4.0	4.1	4.7	6.1	0.016
87	5.6	9.2	12.2	19.2	0.096	6.3	21.3	27.4	36.2	0.200
88	12.3	18.7	23.3	28.5	0.112	6.1	21.4	32.2	39.8	0.231
89*	3.3	5.1	8.0	16.2	0.094	5.6	35.8	44.6	57.2	0.337
90	7.1	11.9	22.4	44.7	0.276	4.9	5.9	10.3	25.1	0.150
92**	3.9	5.3	8.3	13.7	0.072	5.4	6.2	10.0	13.4	0.061
93*	33.6	44.7	46.3	73.5	0.276	58.7	59.7	61.9	64.8	0.045
94**	13.4	15.8	21.9	34.0	0.152	5.6	13.2	16.8	28.9	0.162
95*	26.6	33.7	41.3	65.0	0.277	39.1	41.2	54.5	68.7	0.225
96	3.9	2.8	5.3	11.2	0.057	5.2	5.4	8.4	11.8	0.051
97	2.9	4.7	7.0	12.0	0.066	0.6	0.8	1.6	2.9	0.017
98	2.2	3.8	5.8	10.3	0.059	0.6	0.9	7.0	11.8	0.085
99**	4.5	7.1	10.3	16.2	0.084	2.0	6.8	10.5	29.7	0.199
100*	32.6	40.8	68.0	83.5	0.383	49.1	62.6	74.6	77.0	0.192
101	13.2	24.0	37.3	67.0	0.388	3.0	11.2	28.8	93.9	0.699
102*	34.0	36.1	36.4	39.0	0.034	5.2	11.2	27.0	51.3	0.342
103*	19.9	40.9	56.2	89.0	0.486	80.0	93.5	105.0	144.0	0.457
104*	56.8	71.5	88.3	111.0	0.388	16.0	29.1	56.3	99.0	0.611
105*	23.1	36.6	54.1	92.5	0.502	66.0	88.0	106.0	148.0	0.579
106	18.6	19.9	23.2	39.6	0.155	13.4	24.4	42.1	57.5	0.320

Soil ID	Modified Olsen Extractant: Applied P (mg dm^{-3}) 0	35	70	140	Buffer Coeff.	Mehlich 3 Extractant: Applied P (mg dm^{-3}) 0	35	70	140	Buffer Coeff.
	----- P recovery, mg dm^{-3} -----					----- P recovery, mg dm^{-3} -----				
107	13.2	22.9	35.9	67.2	0.392	12.5	26.0	53.4	92.0	0.585
108	4.4	10.2	15.2	30.9	0.189	1.7	4.0	10.0	22.1	0.151
109	4.7	11.4	17.4	34.0	0.209	5.0	5.2	8.9	20.0	0.113
110	13.0	16.3	19.0	26.0	0.092	4.8	7.0	12.3	27.1	0.165
111	11.3	13.1	15.6	22.1	0.078	3.0	3.5	4.5	8.1	0.037
112	9.2	15.9	22.3	35.9	0.190	0.6	1.4	3.1	5.1	0.033
113	4.9	14.4	20.1	32.8	0.194	4.6	7.1	10.4	14.4	0.070
114*	32.0	50.5	67.0	105	0.520	4.8	7.6	10.7	15.2	0.074
115*	34.6	42.4	58.1	79.5	0.330	31.3	45.6	58.1	60.2	0.199
116*	12.9	20.9	32.2	59.4	0.338	35.9	49.8	60.3	59.5	0.159
117*	6.0	10.4	16.3	30.8	0.180	28.4	30.7	41.6	52.2	0.189

* soils deleted because of high initial P in the check samples
** soils deleted because of high initial P in the original samples

Modified Olsen and Mehlich 3 PBC were correlated with soil properties, first for all soils and then by soil order for the Andisols and Ultisols. The only factors showing a linear relationship were KOH-extractable Al (KOHAl) and Amorphous Al (AmAl) (Table 16). In prior work (Alvarado, 1984; Blakemore, 1983) KOHAl was found to be a quick, reliable estimate equaling about half that of the AmAl in Andisols. In the present set of data KOHAl is about two-thirds that of AmAl.

The relationships between the two forms of extractable Al and the change in soil test P were similar for the two extractants, Modified Olsen and Mehlich 3 (Table 16), and were much better for the Andisols than for the Ultisols. The highest r-value was 0.87 for the linear relationship between MOPBC and AmAl for the Andisols, so 76% of the variation was being explained. However, Alvarado and Buol (1985) found an exponential relationship between MOPBC and Amorphous Al with Andisols which was suggested for use in PDSS in March 1999. With an exponential model, the relationship between MOPBC and AmAl had an R^2-value of 0.78 (Figure 13), that between M3PBC and AmAl had an R^2-value of 0.82 (Figure 14), that between MOPBC and KOHAl had an R^2-value of 0.67 (Figure 15), and that between M3PBC and KOHAl had an R^2-value of 0.64 (Figure 16). Thus the relationships with AmAl were slightly better than those with KOHAl, and those with Modified Olsen were slightly better than those with Mehlich 3.

Table 16. Correlation of soil Al and clay content with the change in Modified Olsen P and Mehlich 3 P in soils analyzed in Costa Rica.

Soils	N	Variable	MOPBC	M3PBC
			---------- r ----------	
All	41	AmAl	-0.55**	-0.52**
		KOHAl	-0.40*	-0.40**
		Clay	-0.03	-0.04
Andisols	18	AmAl	-0.87**	-0.77**
		KOHAl	-0.78**	-0.70**
		Clay	0.02	0.14
Ultisols	21	AmAl	-0.45*	-0.50*
		KOHAl	0.34	0.08
		Clay	-0.29	-0.38

The current observations sent by Eloy Molina were compared with those by Alvarado and Buol data (1985) and the relationship was similar for the two sets of data (Figure 17). There are a number of outliers, more in the Alvarado and Buol data than in the current data by Molina and especially at low levels of AmAl; these seem to cause a reduction in the expected intercept. Nevertheless, this relationship between Modified Olsen P buffer coefficient and the oxalate-extractable Al is the best for determining P fertilizer recommendations for Andisols. Other relationships are also available for Mehlich 3 P buffer coefficient and oxalate-extractable Al, as well as for these two coefficients and KOH-extractable Al. These may be used to make P recommendations on Andisols just as clay content is used to make P recommendations on Ultisols and Oxisols.

Clay content was not related to the change in soil test level per unit of P applied in this set of soils. Although there was such a tendency with clay on the Ultisols, the range in clay content may not have been sufficient to show the effect.

The relationship between M3PBC and clay content from the Costa Rica data also was compared with previous data for the Ultisols which serves as one of the foundations of PDSS. Mehlich 3 P buffer coefficient was similarly related to clay content for the two sets of data (Figure 18). Again, there are some outliers in the relationship, but this may be due to a mixture of clay types, as in some of the Ultisols from Costa Rica there may be both kaolinite and allophane.

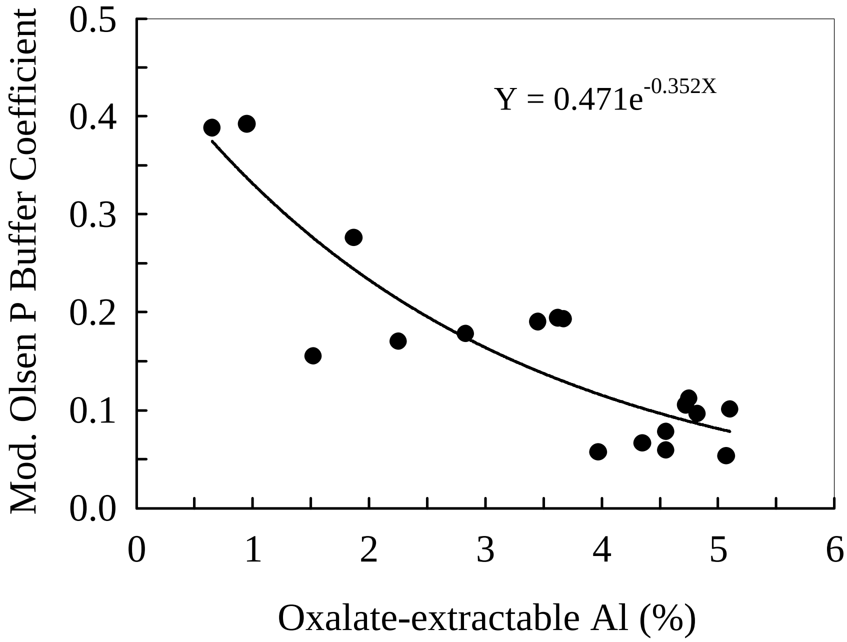

Figure 13. Relation between P buffer coefficients determined by the Modified Olsen extractant and oxalate extractable Al in Andisols

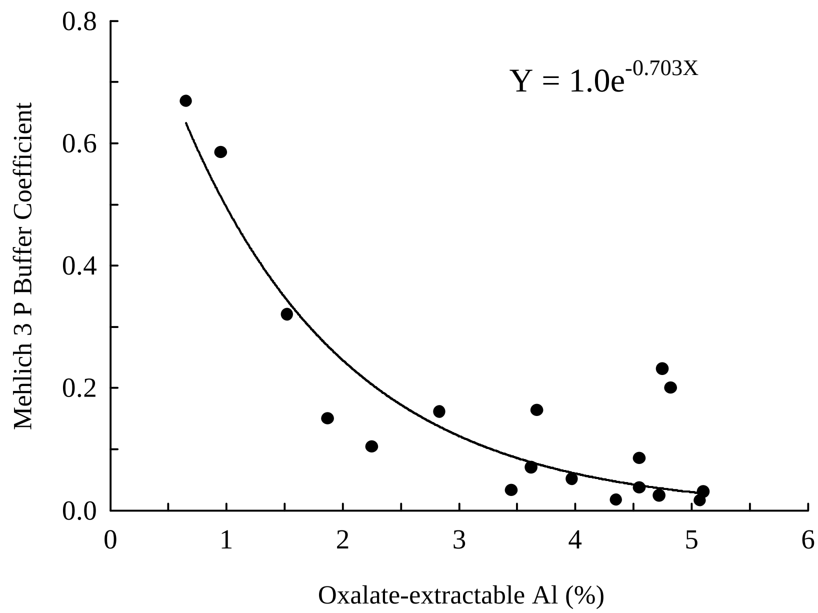

Figure 14. Relation between P buffer coefficients determined by the Mehlich 3 extractant and oxalalte extractable Al in Andisols

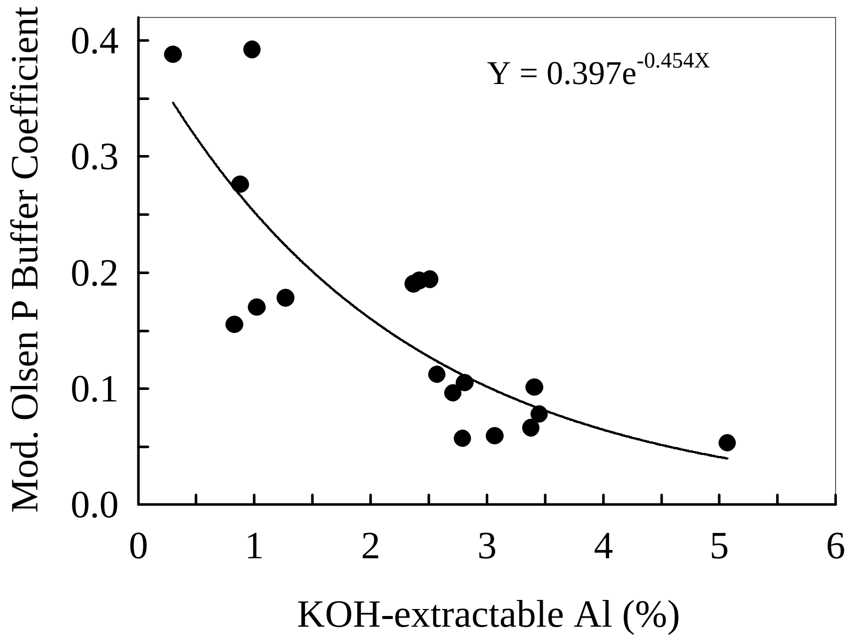

Figure 15. Relation between P buffer coefficients determined by the Modified Olsen extractant and KOH-extractable Al in Andisols.

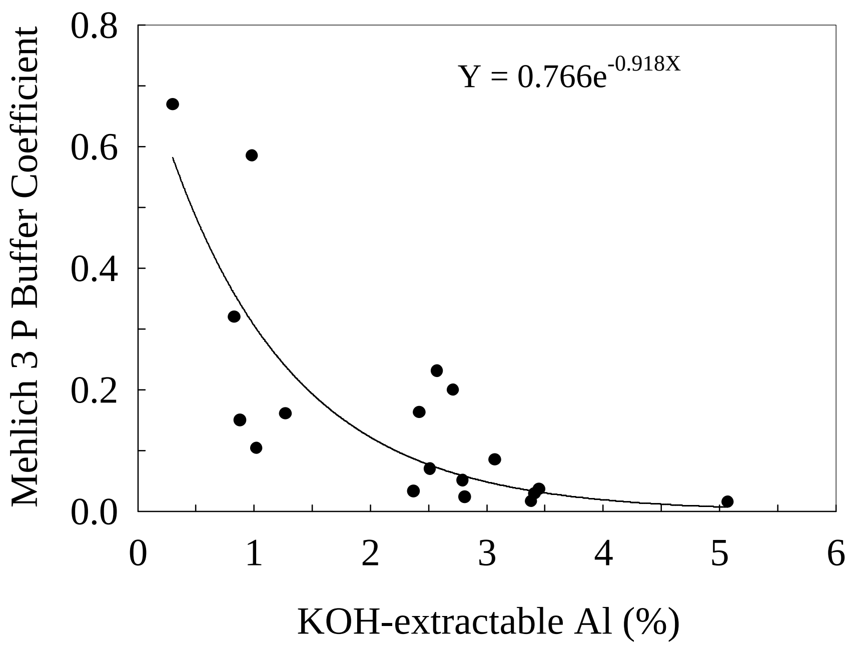

Figure 16. Relation between P buffer coefficients determined with the Mehlich 3 extractant and KOH-extractable Al in Andisols

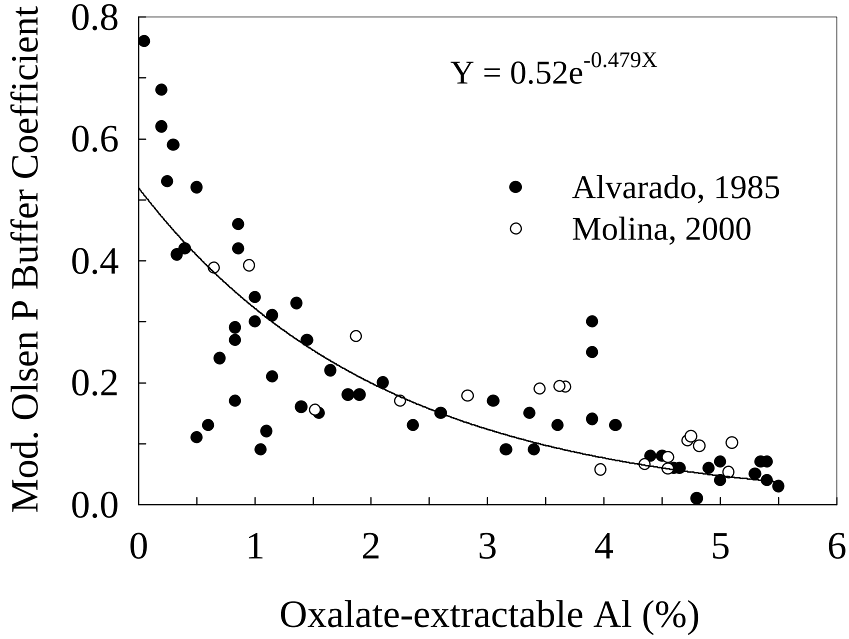

Figure 17. Relation between P buffer coefficients determined with the Modified Olsen extractant and oxalate-extractable Al in Andisols for data reported by Alvarado (1985) and the current data set by Eloy Molina.

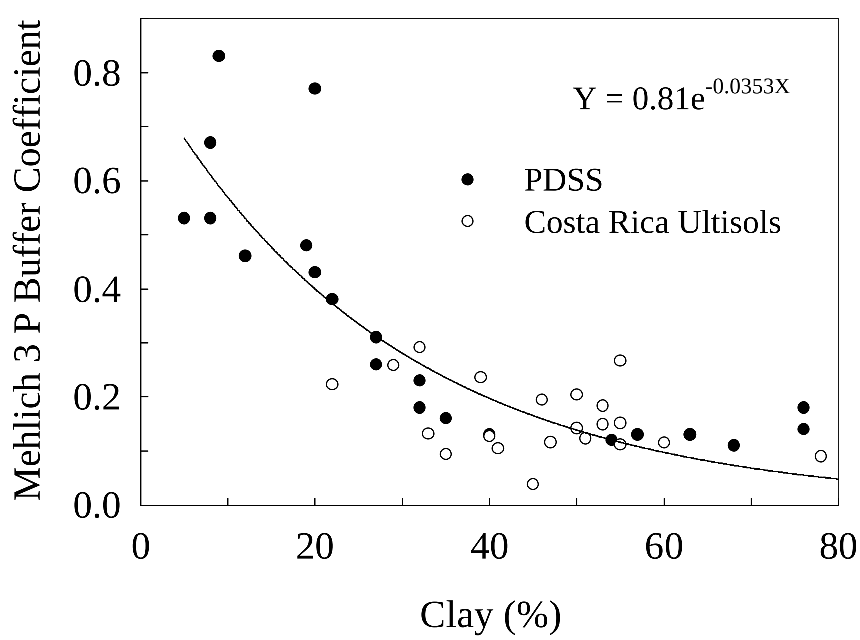

Figure 18. Relation between Mehlich 3 soil P buffer coefficient and clay content for field observations in PDSS and for Ultisols in Costa Rica.

Another observation from the current set of data is that the concentration of P extracted by Mehlich 3 and Modified Olsen are very similar. Sobral and Cox (1998) reviewed concentrations of soil P obtained from various extractants and found Mehlich 3 P very close to Bray 1 P, but that from Modified Olsen was only about 53% of the two former extractants. It is unusual, therefore, to find Mehlich 3 and Modified Olsen to be as close as in the Costa Rica data. It would be valuable to know the cause of this effect.

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Sobral, L.F., and F. R. Cox. 1998. A comparison of soil phosphorus from various soil tests. Background information for IntDSS. Soil Science Department, North Carolina State University, Raleigh.

3. *Determining critical soil phosphorus levels for upland crops* - (Thomas George, Jonathan Quiton, Roger Magbanua, Russell Yost) The yield response to P is considered close to its maximum at a critical soil P level. At higher soil test P levels than considered critical, it is expected that there would be no response to P fertilizer. The intent of P fertilization is then to increase the soil test P to or above this critical level. Several approaches are employed to determine the critical P levels for crops.

   We examined critical soil P levels for upland rice and soybean for several seasons in a long term P experiment (part of IRRI Long Term Experiment (LTPE) network) in an acid upland soil at Siniloan, Laguna, Philippines. Since 1995, five crops each of upland rice and soybean were grown in a upland rice-soybean annual rotation with an initial application in 1995 of 0, 62.5, 125, and 250 and a subsequent application in 1999 of 0, 50, 100 and 200 kg P ha^{-1}. Nutrient amendments other than P were aimed to achieve sufficiency in the crop of all nutrients by liming and applying N, K, Zn for rice and K, Mo and B for inoculated soybean. Soil extractable P was measured by Mehlich 1 (M1P) extractant for each crop at 30 days after P fertilizer application or at seeding of the crop in seasons when no P fertilizer was applied. Critical P levels were estimated by the Cate and Nelson graphical approach or by fitting the linear response and plateau function to yield vs. Mehlich 1 P values.

   The critical soil P levels determined for upland rice and soybean by Cate-Nelson graphical and LRP procedures and the plateau and intercept yields obtained in the different seasons are presented in Tables 17 and 18.

Table 17. Mehlich 1 P critical P levels for rice grown in aerobic soil, Siniloan, Laguna, Philippines

Year	Upland rice variety/line	Critical P level: Cate-Nelson graphical	Critical P level: Linear response and plateau	Plateau yield	Intercept yield
				t ha^{-1}	
1995	IRAT 216	4.0	3.4	1.6	0
1996	UPLRi 5	Scatter	Scatter	2.4	-
1997	IR55423-01	8.7	11.3	3.8	2.8
1998	IR55423-01	4.8	4.7	3.2	2.3
1999	Panay hybrid	2.0	2.1	2.2	1.1
1999	Mestizo hybrid	2.9	2.8	2.6	0.5

Table 18. Mehlich 1 P critical P levels for soybean, Siniloan, Laguna, Philippines.

Year	Soybean variety	Critical P level: Cate-Nelson graphical	Critical P level: Linear response and plateau	Plateau yield	Intercept yield
				t ha^{-1}	
1996	UPSY 2	4.3	4.4	1.5	0.04
1997	UPSY 2	8.0	7.8	3.1	1.60
1998	UPSY 2	4.5	4.5	1.4	0.02
1999	UPSY 2	7.4	9.3	2.7	0.12
2000	UPSY 2	6.6	6.6	2.8	0.22

The Cate-Nelson and the LRP critical levels were comparable with any given season but both varied across seasons. For upland rice, the Cate and Nelson values ranged from 2 to 8.7 while LRP values ranged from 2.1 to 11.3 ug M1P cc^{-1} soil. It should be noted that in the 1996 season, no critical value could be determined for upland rice as no response was observed. For soybean, Cate and Nelson values ranged from 4.3 to 8.0 while LRP values ranged from 4.4 to 9.3 ug M1P cc^{-1} soil. The variability in critical values among seasons appeared not to be related to the build-up or decline of soil P levels or the length of time from applied P. The critical M1P levels, however, tended to be associated with the yield levels; the higher the LRP plateau yield, the higher the critical M1P value (Figure 19) for both upland rice and soybean. It seems, therefore, that at least in the case of soybean, the yield levels attained seem to influence the critical P levels estimated.

The variability in critical P values across seasons would be masked if LRP functions were plotted across seasons with yields relative to the maximum yield in each season (Figures 20 and 21). Thus, the critical M1 P across seasons for upland rice would be 3.4 and for soybean 8.2 ug M1P cc^{-1} soil.

Both Cate and Nelson graphical and the linear response and plateau approaches provide critical levels in a comparable range. Even at the same site, critical P levels varied across seasons and this variability was masked only when relative yields were plotted instead of absolute yields. In the present study, the seasonal variation in critical P level estimates

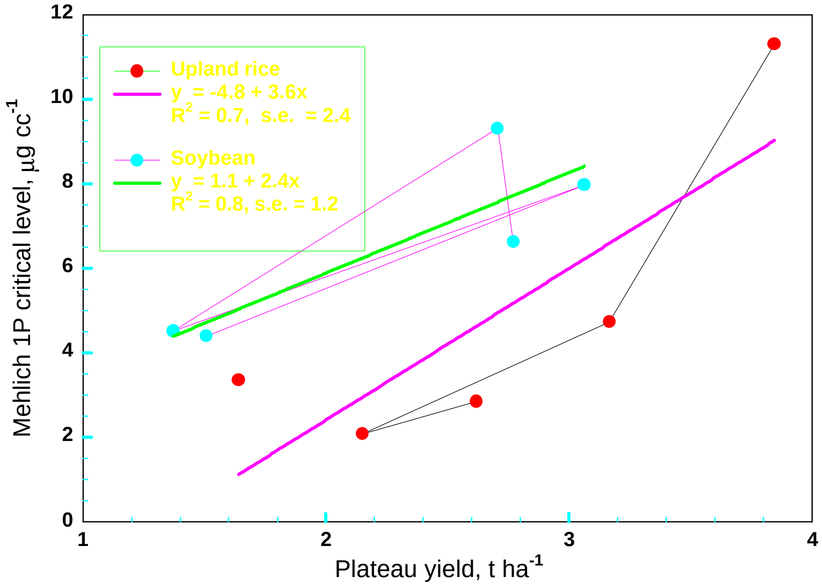

Figure 19. Relationship between the LRP plateau yield and critical Mehlich 1 P value for 5 crops each of upland rice and soybean, Siniloan, Laguna, Philippines.

appeared to be related to yield levels attained. This association with yield level was more obvious in the case of soybean where high plateau yields were achieved in some seasons with relatively unchanged intercept yield. Further studies are needed to confirm whether

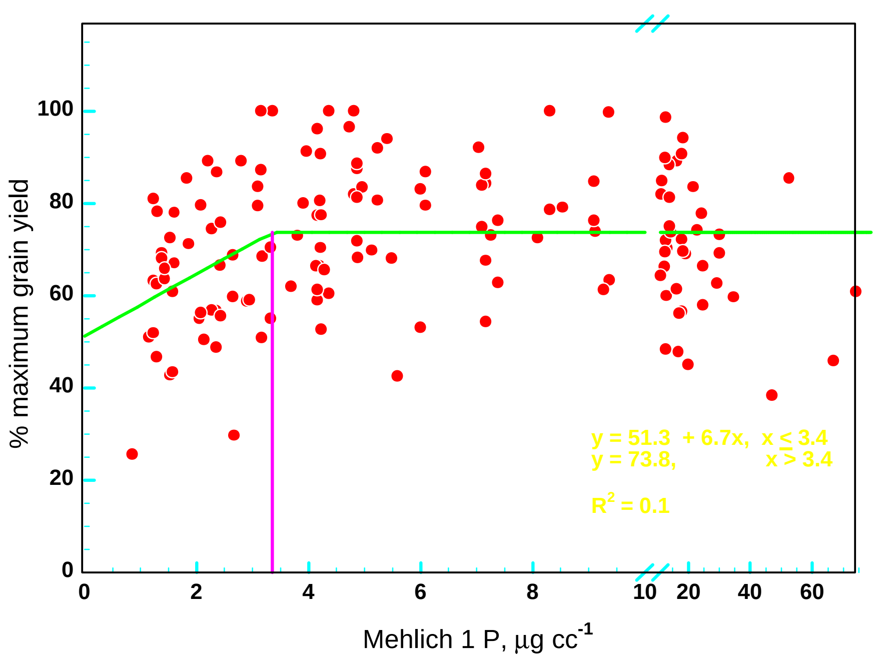

Figure 20. Linear response plateau plot of relative grain yield (expressed as a % of the maximum) against soil Mehlich 1 P for five crops of upland rice, Siniloan, Laguna, Philippines.

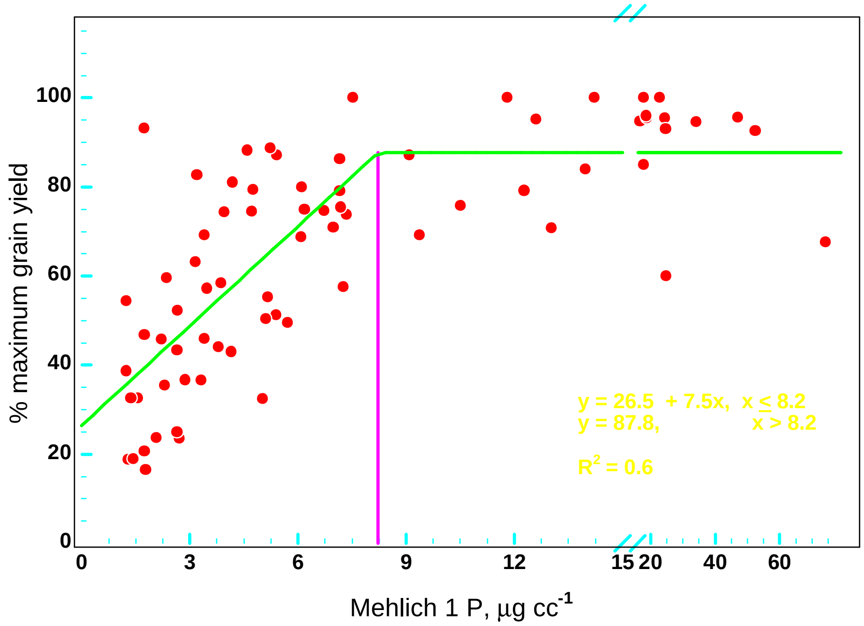

Figure 21. Linear response plateau plot of relative grain yield (expressed as a % of the maximum)

critical level estimations are biased by the range of plateau and intercept yield levels achieved in experiments.

4. *Determining P slow reaction coefficient in the field* - (Thomas George, Jonathan Quiton, Roger Magbanua, Russell Yost) We analyzed the decline in Mehlich 1 extractable P at one of IRRI's LTPE site, Siniloan, Laguna, Philippines. Mehlich 1 extractable P over a period of 973 days for 7 crops of upland rice or soybean grown in a rotation was plotted against P applied at the beginning (Figure 22). The slope of the curve, termed the buffer coefficient was then plotted against time (Figures 23 & 24). The slow reaction coefficient (b) is determined from the equation: $y = a\ b^x$. The estimated slow reaction coefficient (b) per day for Siniloan is 0.9975. In PDSS, a slow reaction coefficient for four months termed Fslow (120 days) ($=b^{120}$) currently has a default value of 0.97. But, the slow reaction coefficient calculated for a 4-moth period at Siniloan would be 0.74, substantially lower than the PDSS default indicating a much more rapid decline of extractable P through slow reaction. Crop P uptake is not accounted for in the decline, but its effect on buffer coefficient or extractable Mehlich 1 P seems to be insignificant compared to that of slow reaction. The next step is to determine whether the slow reaction coefficient should also be used to update PDSS predictions of after harvest extractable P.

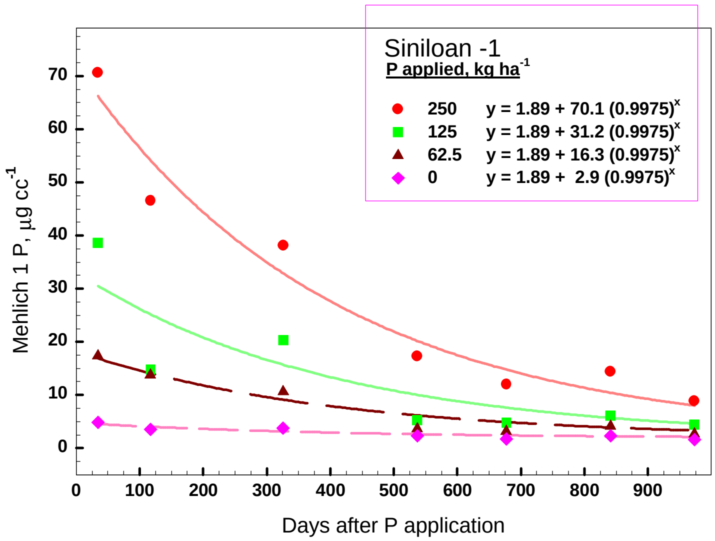

Figure 22. Predicted vs observed decline in Mehlich 1 P using a slow reaction coefficient, b=0.9975.

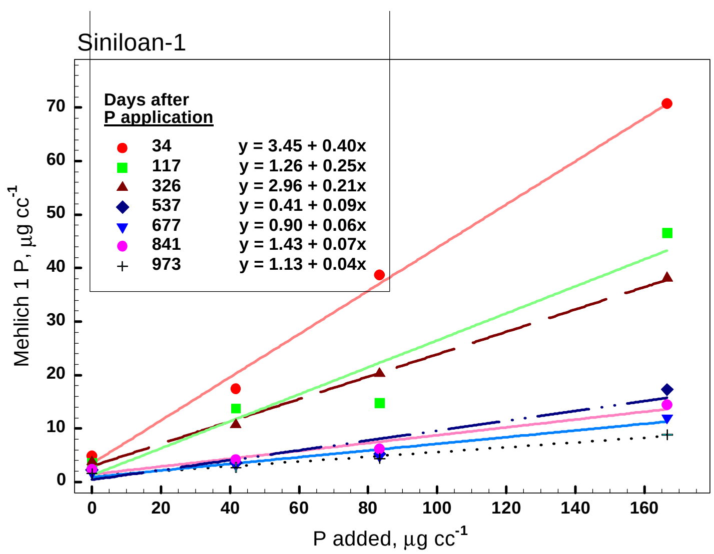

Figure 23. Field determined buffer coefficients (BC) for seven crops of upland rice or soybean grown in rotation starting with upland rice in 1995, Siniloan, Laguna, Philippines.

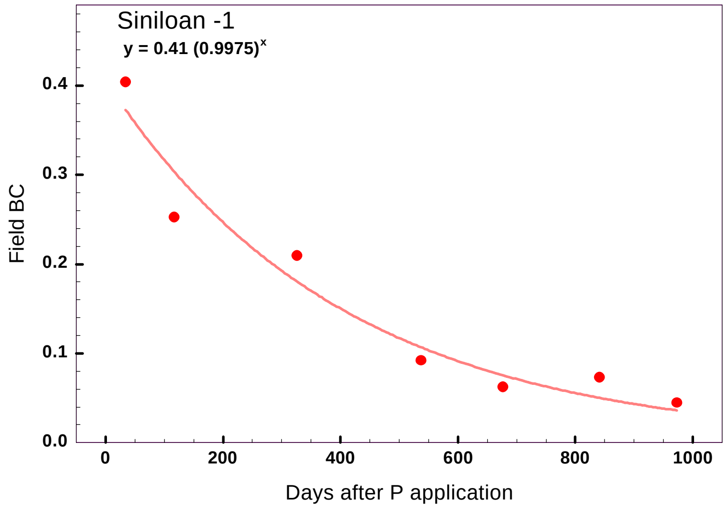

Figure 24. The effect of time on buffer coefficient over seven crops of upland rice or soybean grown in rotation starting with upland rice 1995, Siniloan, Laguna, Philippines.

5. *Improving parameter estimates of LRP using a nonlinear approach* - (Jonathan Quiton, Thomas George, Graham McLaren, Russell Yost) The application of the LRP could be applied theoretically to nutrient response studies where the law of the minimum holds. However, there are cases where the x-variable is a continuous random variable as opposed to the assumptions of the Anderson-Nelson procedure for x to be composed of 'n' levels and 'p' replications. For example, in P response studies, the effect of soil extractable P on yield is studied. Such a variable is continuous and while the Anderson and Nelson procedure may still be feasible, there is a need for a modification of the procedure that removes the restriction on the x-variable.
We postulate an alternative procedure that combines nonlinear regression approach with the ordinary least squares approach in finding the best parameter estimates for the LRP. The nonlinear regression component is used to find the best estimate of the optimum rate (X_o) of the linear response plateau model while the ordinary least squares approach is used to estimate the linear parameters: b_0 and b_1 for the intercept and slope, respectively.
The modified nonlinear regression procedure - The mathematical derivation of the modified nonlinear regression procedure starts with the adaptation of the Anderson and Nelson's definition of the LRP Model IIIj (Anderson-Nelson, 1975 & 1987).

$$Y(LRP) = \begin{cases} b_0 + b_1 x, \; x \le x_0 \\ b_0 + b_1 x_0, \; x > x_0 \end{cases} \qquad (1)$$

where b_0 and b_1 are the intercept and slope linear phase, respectively and X_0 is the optimal rate, (otherwise known as the critical level). Suppose that the optimum rate, $X_{0,}$ is known or is an assigned value anywhere in the domain, then the model can be transformed to a simple linear equation (Equation 2) and therefore, b_0 and b_1 can be solved using the ordinary least squares.

$$Y(LRP \mid x_0 = c) = b_0 + b_1 x^* \qquad (2)$$

where

$$x^* = \begin{cases} x, \text{if } \; x \le c \\ c, \text{if } \; x > c \end{cases} \qquad (3)$$

To illustrate, Figure 25 shows a hypothetical linear response plateau of an experiment with 10 treatment levels as values of the independent variable (x). If the optimum level is 5.0, then Equation 3 compresses all the data points to the right of 5.0 by forcing the value of 5.0 as their x-coordinates. The result is the scatter plot in Figure 26 and therefore, the ordinary least squares estimate will result to similar values for b_0 and b_1.

In the case of a continuous x-variable, the location of X_o is difficult to point to. Therefore, a nonlinear regression is employed to search for the value of X_0, and then use the ordinary least squares to find b_0 and b_1. This is the basic principle of the modified nonlinear regression procedure.

The nonlinear regression component implements two sets of iterations. The first one is the search for the best initial value for X_o at given increments, and the second set is the actual search for the value of $X_{o,}$ once the initial value is determined. Only after the last iteration of the second step that the final values for b_0 and b_1 are determined. The two steps are discussed in detail as follows:

Step 1: Identifying the best initial value for X_{o} . The first step is implemented by assigning a series of values for X_o, and calculating the parameters b_0, b_1 and ESS for each Xo value using Equation 2. The best X_o value in this series is such that ESS is the minimum. This series of Xo values starts with the 2nd X observation, $X_{(2)}$, up to the last observation, $X_{(n)}$ sorted in ascending order. This analysis can be summarized by plotting X_o versus ESS, which shows the response of ESS to changes in X_o.

Equations 4 and 5 shows that the series of X_o values is according to constant intervals (Dx), which is a function of the desired number of divisions (f). Hence, from $X_{(2)}$ to $X_{(n)}$, the total number of iterations is equal to f + 1.

$$X_0 = X_{(2)} + \sum_{i=1}^{k} \Delta x \text{, k=0,1,2,...,f} \qquad (4)$$

where

$$\Delta x = \frac{1}{f}\left(X_{(n)} - X_{(2)}\right) \qquad (5)$$

Step 2: The Nonlinear regression procedure. The second iterative process is the actual search for the best value of X_o, using the nonlinear regression procedure. Let X_o=c where c is identified to be the best initial value from step 1. Therefore, the solution region for X_o is identified to be at c ± Dx. The nonlinear regression procedure can be set up for parameter X_o

using Equation 2 as the model and ESS as the objective function. Any search algorithm may be applied. As in step 1, b_0 and b_1 is determined through OLS.

It should be noted that this procedure is different from a purely nonlinear regression method. In such case, all the parameters b_0, b_1, and X_o have initial parameter values and are simultaneously adjusted to get at a minimum level. Results may or may not arrive at the best solution, since the parameters are related and that the initial parameters may converge to a local minimum rather than the universal minimum. It may also be difficult to show graphically the ESS surface since the ESS, together with b_0, b_1, and X_o constitutes a 4-dimensional space.

Implementation of the Anderson and Nelson procedure for continuous variable data - The scope of the study involves only LRP Models IIIj and IVj , where both are two-line LRP models comprising of an increasing linear trend and a plateau at a given optimum point, which may fall at a design point (Model IIIj) or between two design points (Model IVj). An attempt was made to expand the applicability of the procedure to a continuous x-variable.

Model determination. Anderson and Nelson utilized the modified isotonic regression procedure in the determination of the LRP Model wherein successive moving averages are computed starting at the last observation (i.e, x-values are arranged in increasing order), and the plateau terminates just before MA begins to decrease monotonically (Anderson and Nelson, 1987). Equation 6 was used as the operational definition for the moving average, which is shown in Table 20.

$$MA(Y_j) = \frac{\sum_{i=j}^{n} Y_i}{n-j} \qquad (6)$$

Using hypothetical data as benchmark for the modified nonlinear regression procedure - A hypothetical data set (Table 19, Figure 25) is used as a benchmark to verify whether the modified nonlinear regression method is producing the right solution. For this hypothetical data set, the parameters b_0, b_1, and X_o are predetermined to be 1.0, 1.0, and 5.0, respectively. A series of Xo values was determined by dividing the $X_{(2)}$ to $X_{(n)}$ into 1000 increments, as shown in equation (4). The increment (Dx) is determined be 0.008 such the X_o series consists of 1001 values as follows: X_oÎ {2.000, 2.008, 2.016,...,10.000}. With such number of iterations, a computing software is necesary to calculate the ESS with X_o assuming each value in the series. The result is shown in Figure 27 where the ESS decreased as X_o moves to the right, and increased after passing the value of 5.0.

At the start of step 2, X_o is initialized with a value of 5.0, which is the 626th iteration in step 1. Hence, prior to step 2, the solution region of X_o is identified to be somewhere within 5.0 ±0.008. The objective function is to minimize ESS by changing X_o. The nonlinear regression procedure was applied resulting to an optimum value still at 5.0 and consequently, b_0 and b_1 computed were similar to the predetermined parameter values.

Application of the Anderson-Nelson procedure and the modified nonlinear procedure on P experiments - Table 20 presents two data sets from long term P experiments in Kalayaan and Siniloan, Laguna, Philippines, both on an upland rice-based cropping system on a P-infertile upland. These studies aim to understand P dynamics under a range of soils, soil P supply characteristics, production potentials and phosphate additions in the tropical uplands.

Specifically, these studies are concerned about the effect of available P (Mehlich-1 P, ug g^{-1} soil) on yield. The x-variable is a continuous random variable and Figure 28 shows a LRP behavior for both data sets such that the linear relationship exists up to a certain threshold level after which there is no response.

The parameters of the LRP will be determined both by the Anderson-Nelson approach and the modified nonlinear regression approach. The moving average columns $MA(Y_j)$ beside the response variable (Y) is calculated using Equation 4 and are used for model determination for the Anderson-Nelson approach.

<u>Case1</u>: Upland rice data, Kalayaan, Laguna. Results in Table 21 indicated that the modified nonlinear method computed the optimum level to be at 7.19 ug/g with an ESS value of 6.83. It should be noted that 7.19 appears to be one of the data points for 1994 Kalayaan data. For the Anderson-Nelson procedure, Model IV was first selected since the scatterplot is not clear enough to choose a Model III. By using the moving average information, the cutoff point $X_{(j)}$ is determined by observing the trend of MA starting from the last observation down to the first observation such that "the plateau terminates just before MA begins to decrease monotonically"(Anderson and Nelson, 1987) . In this case, Table 20 shows that MA monotonically decreases from j=3 down to j=0 and hence, X_0, X1,X2, X_3 comprises the linear phase and X_4,X_5,...,X_{15} is the plateau phase. The LRP model is finally identified as Model IV_3, where 3 is the index of the last observation prior to the intersection point or plateau.

Results show that Model IV_3 failed to give the correct parameter values since the condition b1>b2>b3>0 was violated (Anderson and Nelson, 1987). Other Model IV_j's were tried (Model IV_4, IV_5, IV_6), resulting to a solution in Model IV_6 with an ESS of 7.505, but is inferior to the modified nonlinear regression estimates.

However, since it was known from the nonlinear regression results that X_o=7.19 gave the minimum ESS and is one of the observed values, Model III_4 was used. As expected, the results matched with the nonlinear regression estimates.

<u>Case2</u>: Soybean data, Siniloan, Laguna. The modified nonlinear regression procedure resulted with Xo=6.8 ug/g with ESS=2.2. On the other hand, the Anderson-Nelson recommends Model IV_6 based on the moving average result, but didn't produce valid LRP coefficients since the restriction $b_1>b_2>b_3$³0 is violated. Other cutoff points were explored resulting to a solution in Model IV_8, which produced similar results with the modified nonlinear regression procedure.

Implications and limitations of the modified nonlinear regression procedure - Based on the results of the two cases, the following implications are observed. First, the modified nonlinear regression procedure estimates produces similar results to the Anderson-Nelson procedure; however, the former has an advantage because the choice of the model (i.e., if it is Model III or IV) and the cutoff point are analytically determined through the nonlinear regression component. Second, the test data and the hypothetical data indicate that the modified nonlinear regression procedure can be applied to continuous and even to fixed independent variable (x).

In spite of its desirable properties, the modified nonlinear procedure also has limitations. The procedure requires at least two values to the left of the optimum value (X_o). From the same data set, it can be shown that the ESS given X_o with a value between $X_{(1)}$ and $X_{(2)}$ will yield similar results and the solution sets produced is not unique. As a general rule, one must have sufficient data before or after the optimum value to achieve reliable results.

Finally, as inherent in any nonlinear regression, there is a possibility of not arriving at the best solution if the ESS curve does not have a universal minimum. However, as long as the scatter plot of the response shows a strong of a linear and a plateau response, the procedure will arrive at the best solution.

Testing the fitness of the LRP model - The “fitness” of the LRP model can be quantified using the analysis of variance (ANOVA). Tables 22 and 23 show the total variation broken into a) variation due to the LRP model (Model SS) and b) variation due to error (ESS) for the two data sets, respectively. Furthermore, the Model SS can be partitioned to the individual contributions for the linear (b_1) and the optimum rate (X_o) parameters.

Both data sets show that the LRP fits the data sets at 5% level of significance. Furthermore, to isolate the effect of each parameter, Model SS was partitioned into extra sum of squares (Draper and Smith, 1981) due to b_1 and due to X_o. For 1994 Kalayaan data, the effect due to the linear term (b_1) was not significant at 5% because of the two high values present in the data set, whereas it was significant for the 2000 Siniloan data. The effect due to X_0 was calculated by removing the effects of b_0 and b_1 from the Model SS. Results show that both 1994 Kalayaan and 2000 Siniloan data sets show significant effect due to X_o.

Conclusions - The modified nonlinear regression procedure was developed to extend the applicability of the linear response plateau to cases where the x-variable is a continuous random variable, as compared to the Anderson and Nelson procedure, which was developed for experiments in p replications and n treatment levels as x-values. Both methods were tested and compared based on two P experiments in a Philippine acid upland.

Results indicate that the two methods gave similar outcomes; however, the modified nonlinear regression method was more systematic in model detection and parameter estimation since the process is automatically determined in the iteration. On the other hand, the modified isotonic regression used by the Anderson and Nelson procedure on model determination were not able to detect the right cutoff points in the case of 1994 Kalayaan and 2000 Siniloan data. Only after an exhaustive search that the appropriate model was found which matched with the modified nonlinear regression result.

Literature Cited -

Anderson, R. L. and Nelson, Larry A. 1975. A family of models involving intersecting straight lines and concomitant experimental designs useful in evaluating response to fertilizer nutrients. Biometrics 31:303-318.

Anderson, R. L. and Nelson, Larry A. 1987. Linear-plateau and plateau-linear-plateau models useful in evaluating nutrient responses. NCSU Technical Bulletin No.283.

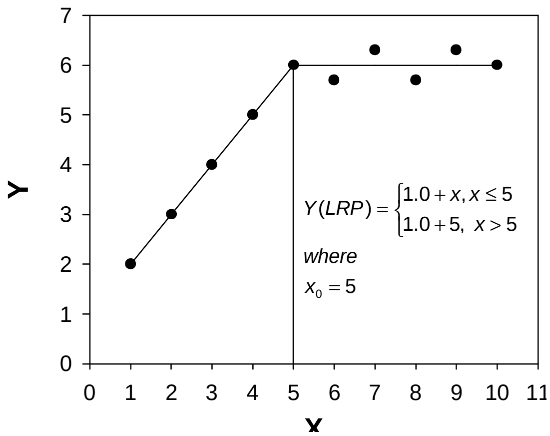

Figure 25. The LRP (Linear Response Plateau) Model.

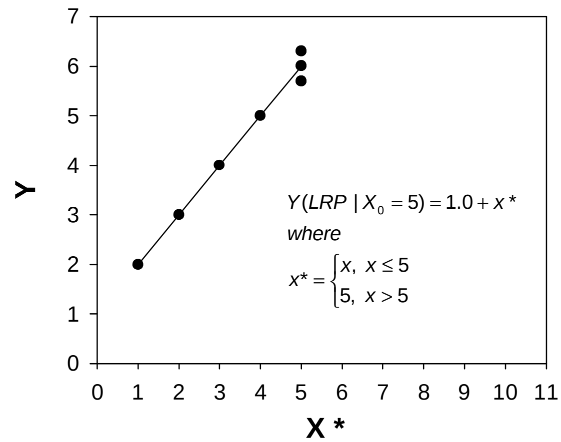

Figure 26. The LRP model, linearized.

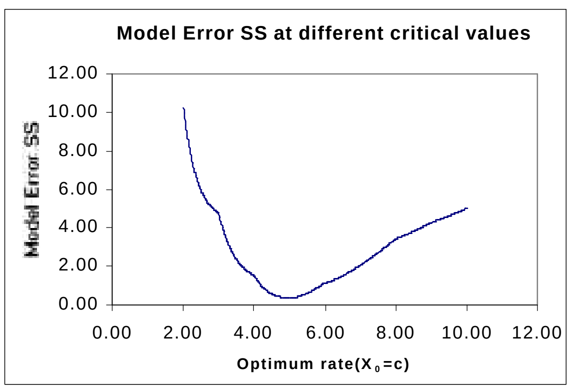

Figure 27. Optimum rate (Xo) vs. Error Sum of Squares using hypothetical data.

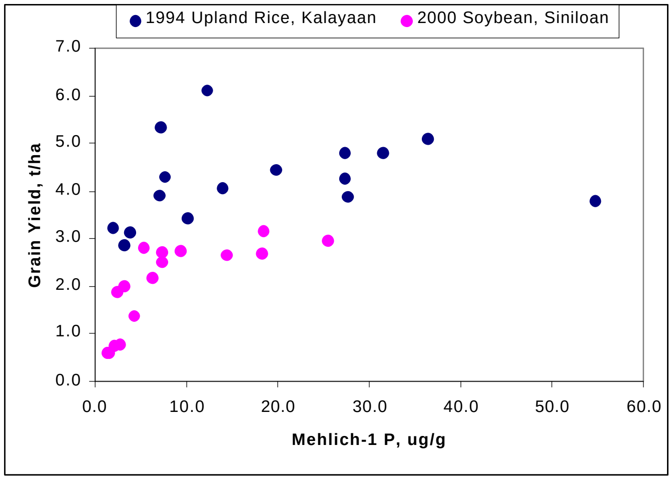

Figure 28. Grain yields versus Mehlich 1 extractable P, Siniloan, Philippines.

Table 19. A hypothetical data showing a linear response plateau

Independent variable(X)	**Response(Y)**
1	2.0
2	3.0
3	4.0
4	5.0
5	6.0
6	5.7
7	6.3
8	5.7
9	6.3
10	6.0

Table 20. Upland rice data from Kalayaan and Siniloan, Laguna, Philippines.

	Upland Rice, Kalayaan, Laguna, Philippines			Soybean, Siniloan, Laguna, Philippines		
Index (j)	Mehlich-1 P, ug/g (X_j)	Grain yield, t/ha (Y_j)	Moving Average MA(Y_j)	Mehlich-1 P, ug/g (X_j)	Grain yield, t/ha (Y_j)	Moving Average MA(Y_j)
0	2.034	3.216	4.209	1.328	0.592	2.020
1	3.230	2.871	4.275	1.476	0.597	2.115
2	3.817	3.122	4.375	2.141	0.746	2.223
3	7.047	3.891	4.472	2.436	1.880	2.337
4	7.190	5.341	4.520	2.731	0.786	2.375
5	7.670	4.290	4.446	3.248	1.993	2.519
6	10.176	3.411	4.461	4.282	1.356	2.572
7	12.339	6.099	4.578	5.389	2.801	2.707
8	13.936	4.055	4.388	6.275	2.170	2.695
9	19.865	4.439	4.435	7.383	2.721	2.816
10	27.356	4.793	4.435	7.383	2.494	2.770
11	27.399	4.274	4.363	9.376	2.752	2.835
12	27.721	3.875	4.385	14.397	2.650	2.856
13	31.574	4.800	4.555	18.383	2.682	2.925
14	36.444	5.087	4.433	18.457	3.156	3.047
15	54.748	3.779	3.779	25.471	2.937	2.937

Table 21. Linear response plateau parameters for modified nonlinear regression and the Anderson-Nelson procedure for upland rice, Kalayaan data and Soybean, Siniloan data.

		LRP Parameters			**Error sum of squares**
		b_o	**b_1**	**X_o**	
A. Upland rice, Kalayaan					
Modified Non-linear Regression		2.139	0.323	7.190	6.825
Anderson-Nelson	IV_3	2.592	0.169	0	0
	IV_4	2.069	0.347	0	0
	IV_5	2.191	0.309	0	0
	IV_6	2.874	0.146	11.641	7.505
	III_4	2.139	0.323	7.190	6.825
B. Soybean, Siniloan					
Modified Non-linear Regression		0.217	0.374	6.821	2.173
Anderson-Nelson	IV_6	0.248	0.352	0	0
	IV_7	-0.020	0.474	5.732	2.178
	IV_8	0.217	0.374	6.821	2.173

X_o cannot be computed and ESS is not applicable since the condition b1>b2>b3$0 (Anderson and Nelson, 1987) is violated.

Table 22. Analysis of variance, upland rice data, Kalayaan, Laguna, Philippines

Source of variation	**df**	**SS**	**MS**	**F**	**Prob>F**
Model *SS(Xo,b_1|b_0)*	2	4.57	2.28	4.35	0.0357
SS(b_1|b_0)	1	0.74	0.74	1.41	0.2559
SS(X_o|b_1,b_0)	1	3.8278	3.83	7.29	0.0182
Residual	13	6.825	0.524993		
Total, corrected	15	11.39			

Table 23. Analysis of variance, soybean data, Siniloan, Laguna, Philippines

Source of variation	**df**	**SS**	**MS**	**F**	**Prob>F**
Model *SS(Xo,b|a)*	2	10.35	5.17	30.95	0.0000
SS(b|a)	1	6.72	6.72	40.18	0.0000
SS(Xo|b,a)	1	3.6307	3.63	21.72	0.0004
Residual	13	2.173	0.167187		
Total, corrected	15	12.52			

External Funding and Support
IRRI: Travel and time cost, experiment estabilshment/maintenance - $45,000

Costa Rica: included in Objective 1, Output 2

Travel and Meetings Attended

- Thomas George - participation in Annual ASA/CSA/SSSA Annual Meetings, Minneapolis, MN.
- Fred Cox -

Relevant Publications, Reports and Presentation at Meetings

Doumbia, M.D., A. Sidibé, A. Bagayoko, A. Bationo, R. A. Kablan, R.S. Yost, L.R. Hossner et F.M. Hons. 2001. Recommandations Specifiques d'engrais: Calibration et Validation du Module Phosphore de Numass. African Crop Science (in review)

George, T., J. Quiton and R. Yost. 2000. Determining Critical Soil Phosphorus Levels for Upland Crops. Poster presented at the ASA-CSA-SSSA Annual Meetings, 5 Nov.- 10 Nov., Minneapolis

Oliveira, F.H., R.F. Novais, T.J. Smyth and J.C. Neves. 2000. Comparisons of phosphorus availability between anion exchange resin and Mehlich-1 extractions among Oxisols with different capacity factors. Commun. Soil Sci. Plant Anal. 31:615-630.

Objective 3 Develop auxiliary tools to the integrated knowledge base to enable local agriculturalists to diagnose and solve soil acidity and nutrient problems that predominate within the social, economic and agronomic characteristics of their regional domains

Output 1 Extensive evaluation network - evaluation of products and capturing knowledge under a variety of location-specific conditions

Within this group we envisage a) individuals with knowledge that should be incorporated into products. b) individuals with field and laboratory data sets that could be used to evaluate products for location-specific conditions, and c) established networks who would be interested and benefit from using our products in their programs. Milestones in activities related to this task are project meetings held in years 1, 2, 4 and 5. Participants would be asked to consider relevance of planned tools to their local needs and suggest potential modifications or additions. In later years we would focus on obtaining feedback on evaluations of NuMaSS and auxiliary tools when applied to their local conditions.

Lead Investigators and Contributors

Deanna Osmond provides overall coordination to activities related to the network, but all U.S. project team members participate as they travel overseas and interact with network members. Collaborators from the following institutions (countries/regions) have agreed to participate in the network, contribute their nutrient management knowledge base and evaluate the decision support software prototypes and auxiliary tools under their location specific conditions:

IBSRAM Steepland Network (Asia)
IRRI Rice Consortium (Asia)
CIMMYT Regional Maize Program (Central America)
Potash&Phosphate Institute Andean Program (Central-Latin America)
IBTA (Bolivia)
ICRAF (Peru)
INIAP (Ecuador)
EMBRAPA (Brazil)
University of Viçosa (Brazil)
SRI (Ghana)
ISRA (Senegal)
Cedara Agric. Res. Station (S. Africa)

Some of these and many others attended the workshop held in Philippines and are active in the network.

Progress

1. *Network member site data pertinent to NuMaSS*
   Phaseolus bean response to liming in Kwazulu-Natal (contribution from Alan Manson and Guy Thibaud at Cedara Agric. Dev. Inst., Pietermaritzburg, South Africa) collaborators at Cedara have been conducting lime trials at various sites with acid soils to characterize dry bean response to liming. Results for trials a four separate locations are summarized in Figure 1. The critical acid (N KCl-extractable Al + H) saturation of the effective cation exchange capacity across all sites was estimated as 15% by non-linear regression. These trials indicate greater acidity tolerance in dry beans than the default value of 0% acid saturation currently

used in NuMaSS 1.5. Inclusion of these data in the software database will serve to alert users to the range of acidity tolerence among dry bean cultivars and locations.

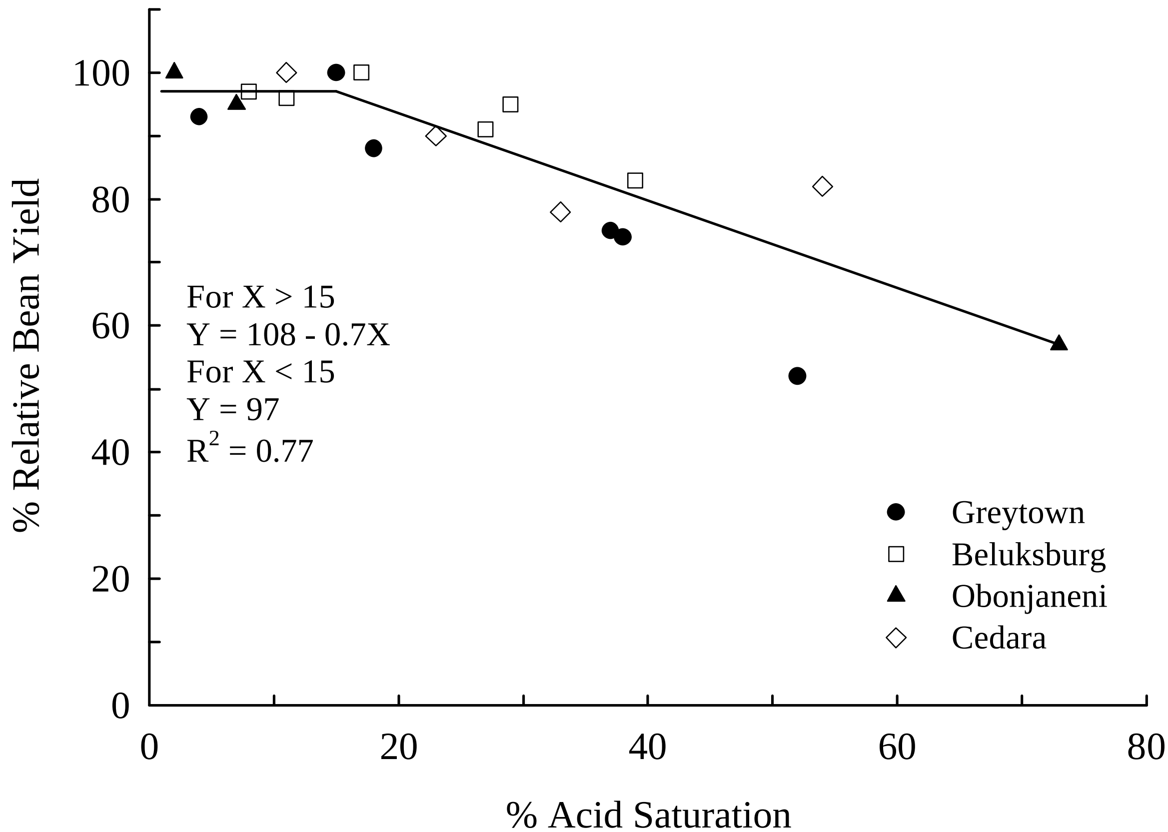

Figure 1. Dry *Phaseolus* relative bean yield as a function of soil acid saturation % of the effective cation exchange capacity in lime trials with four soils in the Kwazulu-Natal region of South Africa. (data provided by Alan Manson and Guy Thibaud, Cedara Agric. Dev. Inst., Pietermaritzburg)

Soil and bean yield data for the trial at Cedara are shown in Table 1. Lime with 86.7% $CaCO_3$ equivalence was incorporated to a 30-cm depth, whereas soil chemical properties are reported for a 15-cm sampling depth. Rates of lime presented in the table were, therefore, adjusted to half of the actual field applications to coincide with the soil sample data. The lime recommendation by NuMaSS 1.5 to achieve 15% acid saturation in this soil, assuming a bulk density of 1 g cm^{-3}, 15-cm depth of incorporation and with the quality of lime used, was 3 ± 0.75 t ha^{-1}. However, soil analytical data reveals that 3 t lime ha^{-1} only reduced acid saturation to 33%. Further inspection of the data in Table 1 reveals that under-estimation of the lime requirement is due to the lime neutralization factor. In NuMaSS a lime neutralization factor of 1.9 $cmol_c$ of Ca from lime / $cmol_c$ of acidity is used, based on lime experiments with Inceptisols, Oxisols and Ultisols in Sitiung, Indonesia (Wade et al., 1987. Liming in transmigration areas. pp. 125-131. *In* N. Caudle and C.B. McCants (eds.) TropSoils Technical

Report 1985-1986. North Carolina State University, Raleigh, NC). However, soil chemical data for this experiment indicates that the observed lime neutralization factor was 1.74 $cmol_c$ of Ca from lime / $cmol_c$ of acidity. Based on numerous experiments in the region, lime recommendations by the Cedara Agric. Dev. Inst. use a higher lime neutralization factor than the default value in NuMaSS. With the help of collaborators throughout the network soil analytical and lime quality data from various experiments are being assembled to compare lime neutralization factors for a variety of soils. Results from this comparison may lead to adjustments in the lime neutralization factor, prior to the release of NuMaSS version 2.0.

Table 1. Soil chemical data and dry *Phaseolus* bean yields for lime treatments on the Hutton soil at Cedara Agric. Dev. Inst. near Pietermaritzburg, South Africa[a].

Applied	**Exchangeable**				**Acid**	**pH in**	**Bean**
Lime[b]	**Ca**	**Mg**	**K**	**Al+H**	**Sat.**	**KCl**	**Yield**
t ha^{-1}		---------- $cmol_c$ L^{-1} ----------			%		kg ha^{-1}
0	1.40	0.78	0.36	2.94	54.00	4.00	2364
3	2.13	1.46	0.38	1.95	33.00	4.10	2251
5	2.44	1.84	0.36	1.40	23.00	4.30	2582
6.5	3.25	2.63	0.37	0.71	11.00	4.50	2878
$LSD_{0.05}$	0.39	0.41	Ns	0.53	10.00	0.10	

[a] Data contributed by Alan Manson and Guy Thibaud, Cedara Agric. Dev. Inst.

[b] 50% of the lime with 86.7% $CaCO_3$ equivalence incorporated to a 30-cm depth to coincide with soil data from samples taken to a 15-cm depth.

<u>Immediate and long-term P sorption in Ecuador soils used for potato production</u> - (contribution from Jose Espinosa of INPOFOS, Juan Cordova and Franklin Valverde of ‘Santa Catalina’ Experiment Station, and Francisco Mite of ‘Pichilingue’ Experiment Station, with analytical support from Fred Cox) Data were collected in Ecuador from two field experiments in which fertilizer P had been applied at various rates and times for a period of three years. The model developed by Cox, et al (1981) was used to determine the immediate and long-term P sorption in these studies. The original model utilized the data from an initial application of P to assess immediate and long-term P sorption, and the results could then be used to compare predicted with actual conditions if re-applications or later applications were made. This was done by solving at various times in a pulsating manner. In the current data sets only four of the 12 treatments had just an initial application, so, to more fully utilize the information, a statistical program in SAS was developed to consider the data from all 12 treatments. That program is as follows:

```
data one; input Site Time Tmt F0 F1 F2 P;   peq=5;
      Comment  Site is numbered 1 or 2, Time is in years after
```

```
       application, Treatment is the ID number, F0, F1, and F2 are the kg P/ha
       applied at times 0, 1, 2 yr, P is the Modified Olsen P, and peq is the
       minimum value of Modified Olsen P allowed for that soil;
cards;  (data can be provided upon request)
title Both Sites;
proc nlin;  parms a=16 b=0.3, c=0.4; bounds b<=1,  c>=0;
if f0>=0 and f1=0 and f2=0 then do;
     model p=(a+b*f0-peq)*exp(-c*time)+peq;
     end;
      Comment This is the basic model for an application at Time zero and no
      further applications (Treatments 1 through 4);
      Comment Estimates will be made of "a", the initial Modified Olsen P at
      time zero, "b" the fraction of the fertilizer P that will be present in
      the soil test P, and "c" which indicates the rate of decrease of the
      soil test P in time;
else if f0=0 and f1=0 and f2>0 and time<2 then do;
     model p=(a+b*f0-peq)*exp(-c*time)+peq;
     end;
      Comment This statement if for Treatment 5 for periods up until Time 2
      when the fertilizer is applied;
else if f0=0 and f1=0 and f2>0 and time>=2 then do;
     model
p=(((a+b*f0-peq)*exp(-c*2)+peq)+b*f2-peq)*exp(-c*(time-2))+peq;
     end;
      Comment The first part of this function calculated the "a" at Time
      equals 2 while the remainder solves the function for the period of time
      greater than 2;
else if f0=0 and f1>0 and f2>0 and  time<1 then do;
     model p=(a+b*f0-peq)*exp(-c*time)+peq;
     end;
      Comment This is the beginning of the functions for Treatment 6, in which
      fertilizer was applied at Times 2 and 3.  The same approach and logic as
      used above may be seen in all the following statements;
else if f0=0 and f1>0 and f2>0 and 1<=time<2 then do;
     model
p=((a+b*f0-peq)*exp(-c*1)+peq+b*f1-peq)*exp(-c*(time-1))+peq;
     end;
else if f0=0 and f1>0 and f2>0 and time>=2 then do;
     model p=(((a+b*f0-peq)*exp(-c*1)+peq+b*f1-peq)*exp(-c*2)+peq
+b*f2-peq)*exp(-c*(time-2))+peq;
     end;
else if f0>0 and f1>0 and f2=0 and time<1 then do;
     model p=(a + b*f0-peq)*exp(-c*time)+peq;
     end;
else if f0>0 and f1>0 and f2=0 and time>=1 then do;
     model
p=(((a+b*f0-peq)*exp(-c*1)+peq)+b*f1-peq)*exp(-c*(time-1))+peq;
     end;
else if f0>0 and f1>0 and f2>0 and time<1 then do;
     model p=(a+b*f0-peq)*exp(-c*time)+peq;
     end;
else if f0>0 and f1>0 and f2>0 and 1<=time<2 then do;
     model
p=(((a+b*f0-peq)*exp(-c*1)+peq)+b*f1-peq)*exp(-c*(time-1))+peq;
     end;
else if f0>0 and f1>0 and f2>0 and time>=2 then do;
     model
```

```
p=((((((a+b*f0-peq)*exp(-c*1)+peq)+b*f1-peq)*exp(-c*2))+peq)
+b*f2-peq)*exp(-c*(time-2))+peq;
     end;
output out=new predicted=py;
proc print;
proc plot; plot py*p/haxis=0 to 100 by 10 vaxis=0 to 100 by 10;
      Comment Both the observed and predicted values of Modified Olsen P may
      be plotted with Time, but the pulsating nature of the curve makes it
      difficult to view well in this case;
run;
```

When the new statistical package was run on the combined data from the two sites, the estimated "a" was 21, "b" was 0.31, and "c" was 0.19. Greater stability is achieved if the coefficients "b" and "c" are combined into one term indicative of P sorption (Cox, 1994). When this is done for the most convenient and practical time of one year, 26% of the applied fertilizer would be in the Modified Olsen P, so 74% of the P had been sorbed to an "unavailable" form. The predicted Modified Olsen P was plotted against the observed Modified Olsen P for the combined data from the two sites and the relationship was reasonably close to the expected 1:1 (Figure 2). However, both the intercept and slope were significant in the relationship Y = 11.7 + 0.67X and the r-square value was 0.64.

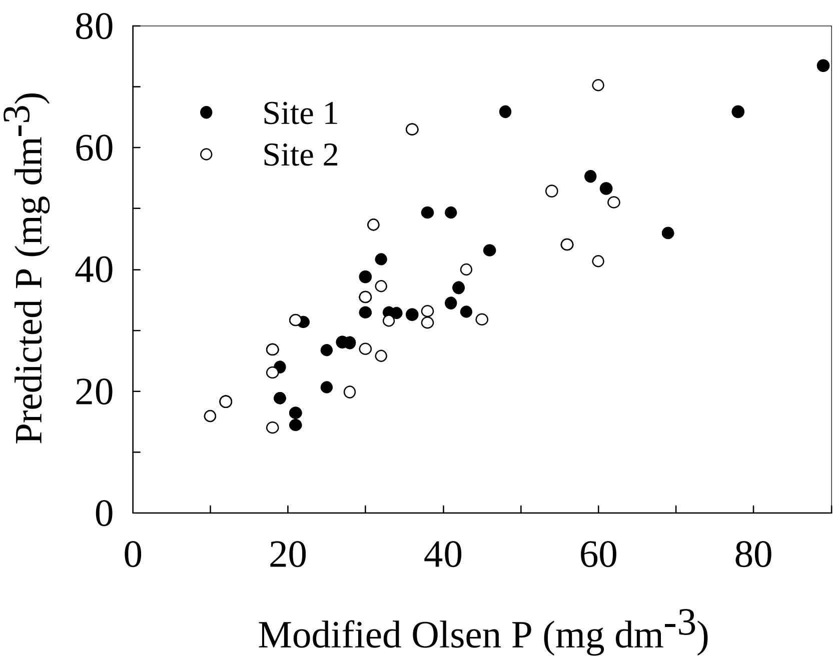

Figure 2. Relation between predicted and observed Modified Olsen P for soils under potato production for three years at two sites in Ecuador.

The sites were also analyzed individually and gave markedly different interpretations of P sorption. For Site 1 the a, b, and c values were 24, 0.40, and 0.29, respectively. At one year

30% of the applied P would be shown in the Modified Olsen P. The relationship between PY and P, Y = 8.6 + 0.77X had an r-square value of 0.76. The data for Site 2 failed to converge in the NLIN program of SAS, but gave a, b, and c coefficients of 16, 0.19, and 0. Thus there was no time effect for long-term sorption and at one year 19% of the P applied would be shown in the Modified Olsen P. In this case the relationship between PY and P, Y = 10.9 + 0.66X had an r-square value of 0.60.

The reason that the Site 2 data did not converge in NLIN was that the soil test P measured in the check plots increased during the three years. This is not logical as there would naturally be a decrease due to P removal and other P sorption during this time. However, in a biological system there are annual differences affecting the level of P extracted and if this variation is not random, but increases each year, then this can happen. This is less likely to occur in data sets of longer periods.

It is unfortunate that the short terms of these two potato data sets resulted in questionable coefficients for the model. Field data is needed for comparison to coefficients determined in the laboratory to confirm their validity. For the time being, however, the coefficients found with the combined two sets may be used as a first approximation.

Reference Cited -

Cox, F.R., E.J. Kamprath, and R.E. McCollum. 1981. A descriptive model of soil test nutrient levels following fertilization. Soil Sci. Soc. Am. J. 45:529-532.

Critical soil P levels for potato production - (contribution from Jose Espinosa of INPOFOS, Juan Cordova and Franklin Valverde of ‘Santa Catalina’ Experiment Station, and Francisco Mite of ‘Pichilingue’ Experiment Station, with analytical support from Fred Cox and Jot Smyth) NuMaSS 1.5 does not contain sufficient information to provide a diagnosis or fertilizer P recommendation for potato. Among the missing pieces of information are critical soil P values from field trials were yield response has been characterized across a broad range of soil P levels. Experiments at the two sites with Andisols in Ecuador provide the desired information for definition of a critical soil P level for potato.

Each site contained three years of potato yield data. In the first year four P treatments of 0, 33, 66 and 99 kg P ha^{-1} were established. In subsequent years these plots were sub-divided and residual fertilizer P was compared with fresh applications of the same P rates. There was about a 4-fold variation in Modified Olsen-extractable soil P among P treatments at each site and within each year of the experiment.

Critical soil P levels were first estimated via non-linear regression across crop years for each site. In both sites, however, the relation between relative yield and Mod. Olsen P for the third year deviated considerably from the two initial years. Exclusion of year 3 data changed the critical soil P estimate from 42 to 36 mg P dm^{-3} for site 1 and from 38 to 32 mg P dm^{-3} for site 2. Due to the small difference in estimated critical soil P values between sites, the two initial years for each Andisol were combined to provide the relation shown in Figure 3 with an estimated critical soil P level of 38 mg P dm^{-3}. The resulting critical soil P value from data in Ecuador is similar to the value of 40 mg P dm^{-3} used for potato production on Andisols in Costa Rica (Eloy Molina, personal communication). These values are also considerably higher than the Mod. Olsen values of 10 - 15 mg P dm^{-3} which are generally used for crops like corn throughout the Central American region.

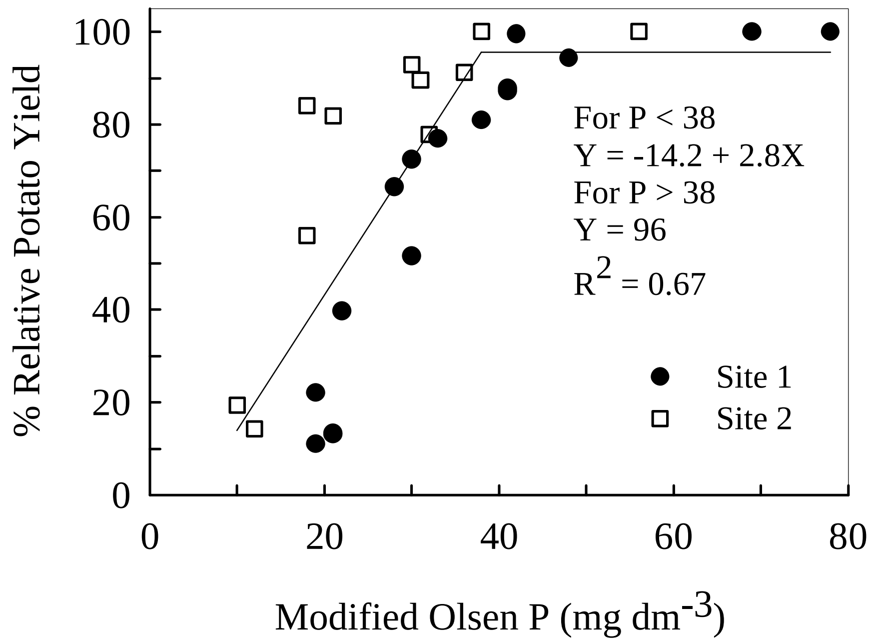

Figure 3. Relation between potato yield and Mod. Olsen extractable P for two crop cycles at two separate sites on Andisols in Ecuador.

The critical soil P level for Andisols in Ecuador was compared with data for P fertilization trials with potato on 19 sites in Western Australia (Hegney et al., 2000). Soil classification for these sites was not given but clay content varied from 2 to 9%. For each of these sites, the authors related % relative yield to fertilizer P using regression equations in the form of $Y=a\text{-}be^{-cX}$. Responsiveness to fertilizer P was assessed as the proportion *b/a*, and this yield factor was related to Colwell extractable soil P (Figure 4). There was negligible yield response to fertilizer P above 97 ug g^{-1} of Colwell soil P. In their review of P fertilization research in South Australia, Reuter et al. (1995) found that linear regression slopes between Colwell (*y*) and Olsen (*x*) soil P tests for seven regions varied from 1.8 to 2.4 with a mean value of 2.1. Based on this mean value, the critical Colwell soil P value of 97 ug g^{-1} would correspond to 46 ug g^{-1} with the Modified Olsen extractant.

References Cited -

Hegney, M.A., I.R. McPharlin and R.J. Jeffery. 2000. Using soil testing and petiole analysis to determine phosphorus requirements for potatoes (*Solanum tuberosum* L. cv. Delaware) in the Manjimup-Pemberton region of Western Australia. Aust. J. Exp. Agric. 40:107-117.

Reuter, D.J., C.B. Dyson, D.E. Elliott, D.C. Lewis and C.L. Rudd. 1995. An appraisal of soil phosphorus testing data for crops and pastures in South Australia. Aust. J. Exp. Agric. 35:979-995.

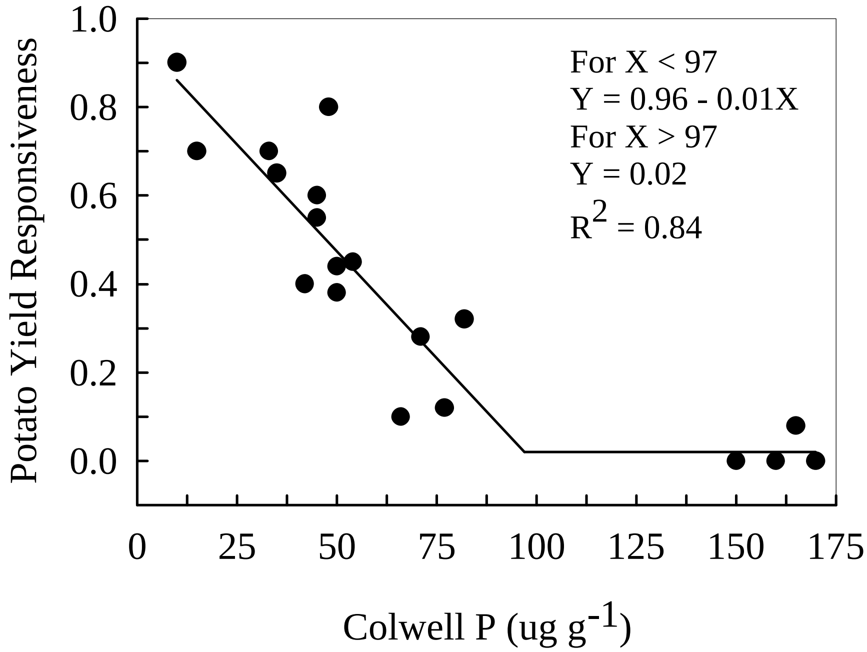

Figure 4. Relation between potato yield responsiveness to applied fertilizer P and Colwell-extractable soil P for 19 field trials in Western Australia. (adapted from Hegney et al., 2000).

2. *On-farm testing of the PDSS module in Thailand* - (T. Attanandana, T. Vearasilp, K Kukiet, S. Kongton and R. Yost) Phase one results of the Thailand Research Fund project have indicated that suitable predictions of N requirements were predicted for each of the major soil series used for the growing of maize in central Thailand (Attanandana et al., 1999). The phase two objectives of the project were to identify P needs and to attempt to predict responses using the PDSS nutrient management software. The results presented here evaluate the first season's comparisons among ways to estimate the P fertilizer requirements in the maize-growing soils of Central Thailand. Two groups of fields were prepared by TRF project staff, including Pioneer and CP companies. Because PDSS and NuMaSS represent four components of nutrient management information processing (diagnosis, prediction, economic analysis, and recommendations), we analyze the results successively for the diagnosis and prediction components in this report.

   Diagnosis component - In order to assess the success of the on-farm tests with respect to diagnosis we first look at the data, usually observational, historical, but also the soil and plant analysis data available for each site.

   The PDSS diagnostic module will analyze as many as seven criteria in making a diagnosis, however we only are checking the soil P levels as extracted by Mehlich1 and Olsen extractants in this comparison. The data indicate that there was a good range of soil test P levels – from less than 1 to nearly 20 mg kg^{-1} (Table 2). Such a wide range in values should be excellent for testing the ability of the software to diagnose P responsive and unresponsive conditions. The first important conclusion from these data was that there was excellent agreement between the test kits and the laboratory determined intervals of P availability (Table 2, last line). In terms of class comparisons, 8 of the 10 classes matched for the two approaches to measure soil test P. There was, in fact, closer agreement between the test kit and the laboratory than there was between the two extractants Mehlich 1 and Olsen. We suspect that this might be due to the neutralization of the acidic Mehlich extractant by the free calcium carbonate in several of the maize soils. Comparisons among the laboratory and kit determined nitrate and potassium were also indicated good agreement. Results from the five CP company fields was apparently more successful, however, indicating that the diagnostic methods accurately detected fertilizer responsive conditions (Table 3).

Table 2. Soil test data of the pioneer company's plot (before planting)

Series	NO_3^- content			P content					K content			Response	
	Spectrophotometer		Test Kit	Spectro(Mehlich)		Test Kit	Spectro(Olsen)		Test Kit	A.A			
	mg/kg N	level		mg/kg P	level		mg/kg P	level	mg/kg K	mg/kg K	level	Predict	Observ
Lb	2.00	VL	VL	4.50	M	H*	8	L	M	80	M	-	-
Lb	18.00	L	L	0.25	VL	VL	6	L	H	130	H	+	-
Lb	3.47	VL	VL	3.50	M	M	4	L	M	82	M	-	+
Ln	4.38	VL	L	6.75	M	H*	11	M	M	89	M	-	+
Ln	4.37	VL	VL	1.00	L	L	5	L	M	71	M	+	+
Tk	2.67	VL	L	3.25	L	L	17	M	H	277	H	+	-
Tk	12.92	L	L	0.56	L	VL	6	L	H	174	H	+	+
Pc	7.00	VL	L	6.00	M	M	6	L	L	39	L	-	-
Ct	3.00	VL	VL	2.00	L	L	4	L	M*	266	H	+	+
Lb	18.00	L	L	19.60	VH	H	22	H	H	628	H	-	-
		10/10			***8/10***					***9/10***		***6 = 0.2***	

Table 3. Soil test data of the CP company's plot (before planting)

No	series	NO_3^- content			P content					K content		Response	
		Spectro		Test Kit	Spectro (Mehlich)		Test Kit	Spectro (Olsen)		Test Kit	A.A		
		ppm N	level		ppm P	level		ppm P	level	ppm K	ppm K	Pred	Obs
1	Cu	1.25	VL	VL	10.00	VH	H	8.0	L	L	69	-	-
2	Lb	1.56	VL	VL	47.50	VH	VH	26.0	H	L*	84	-	-
3	Wi	15.00	L	M	4.41	M	M	9.0	L	H	106	-	-
4	Tk	12.00	L	L	1.25	L	VL	8.0	L	H	126	+	+
5	Pc	12.00	L	L	9.00	H	H	11.0	M	M	78	-	-
Agreement:				***4/5***			***5/5***				***4/5***	***6 = 1.0***	

Olsen's: 0-9=L, 10-20=M, >21=H

The second test of the diagnosis phase is to determine if the soil tests correctly identified P responsive soils to which P applications would result in increased yields (Cai et al., 1996).

This can be done by forming a matrix similar to that in Table 4, and calculating the coefficient kappa, which expresses the agreement between the diagnosis and the field-determined results..

Table 4. Diagnosis accuracy assessment: Pioneer Company

	No response	Response
No diagnosis (not deficient)	3	2
Diagnosis (deficient)	2	3
		Kappa coefficient = 0.20, n=10

The matrix is composed of the Diagnostic test (in this case soil tests) on the left and the actual response in the columns on the top. The kappa statistic summarizes the extent to which "No response" situations were detected by the diagnostic test, soil analyses in this case. Kappa values of 1 indicate perfect prediction, i.e. there was no response to fertilizer P when the soil test P was in the Medium or High categories and there was always a response when the soil tests were less than Medium, i.e. Low or Very Low. Kappa values of 0 indicate that there was just as many incorrect diagnoses as correct ones or that the diagnostic test was no better than chance alone. The kappa analyses of the Pioneer experiments indicated that the soil tests were useful in identifying P or fertilizer responsive situations (Table 4). Kappa analyses of the CP company's results, however, gave higher values than those from the Pioneer experiments (K = 1.0 versus K = 0.2) (Table 5). There were, however, slight differences in the amounts of K and N applied so it is possible that some of the responses were not, in fact, due solely to P. We suggest that future on-farm tests seek to vary only one nutrient so that comparisons / updates of the critical level can be obtained from such studies.

Table 5. Diagnosis accuracy assessment: CP Company

	No response	Response
No diagnosis (not deficient)	4	0
Diagnosis (deficient)	0	1
		Kappa coefficient = 1.0, n=5

Table 6. Diagnosis accuracy assessment: Pioneer Company & CP Company

	No response	Response
No diagnosis (not deficient)	7	2
Diagnosis (deficient)	2	4
		Kappa coefficient = 0.44, n=15

<u>Prediction component: estimating P critical levels</u> - Prediction of P requirements is heavily influenced by the target critical levels, therefore we also compared the PDSS prediction of soil

P critical levels with local estimates. The estimates of P critical level used in PDSS are based on % clay using results largely developed on highly weathered soils of Brazil (Lins and Cox, 1989). Our hypothesis was that the prediction of critical level based on clay percentage alone may not apply to the mix of weathered soils of Thailand, sandy, red soils and the black smectitic soils.

It is likely these two categories of soils contain different amounts of P and will require different amounts in order to restore their productivity to the potential as estimated from the DSSAT maize model (Attanandana et al., 2000). Project data were analyzed according to the LRP fitting routine developed by X. Shuai (2000, unpublished data) with PROC NLIN of SAS v. 8.0.

Results of the plotting and estimation of the critical levels of the red, sandy soils are given in Figure 5. The LRP equation was estimated as Yield = 66.87 +49.568*(Min(X, 8.26)), which indicates a critical level of Bray II of 8.26, approximately 2.4 mg P kg^{-1} (Attanandana, personal communication). This graph also shows the common occurrence that quadratic equations of critical level, yield response, and other functions, often over-estimate the critical levels and x values – a point long emphasized in Anderson and Nelson (1975).

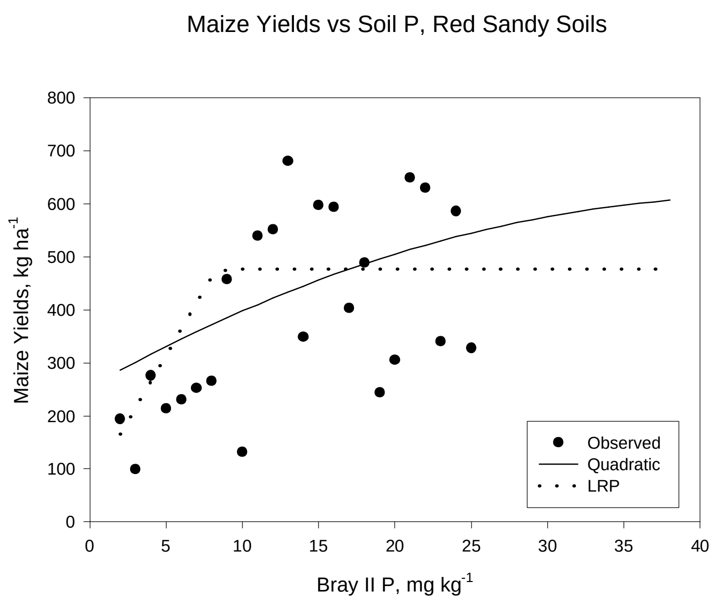

Figure 5. Estimated critical level, red, sandy soils.

An attempt to estimate the critical level for the black soils is shown in Figure 6, but indicates that the data are scarce. A best estimate, however, is that the level is approximately 14.6, which corresponds roughly to a Mehlich1 of 4 mg kg^{-1}.

These results contrasted with the results suggested in Lins and Cox (1989) and Cox (1994), who found that as the % clay increased the critical levels decreased. They also found that as the % clay increased the buffer coefficient (defined as the change in extractable P / unit of applied P, decreased (data not shown).

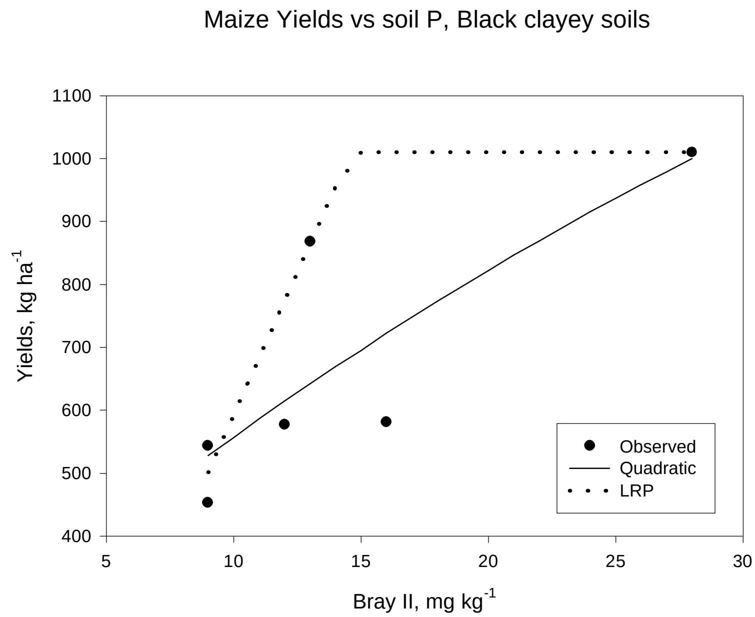

Figure 6. Estimated critical level, black soils.

<u>Prediction component: estimating the amounts of P needed</u> - In this component we try to analyze the question were the correct amounts of P recommended by PDSS? In order to answer this question precisely expensive factorial experiments should be conducted at each site, obviously costing a great deal of time and money. Another way to answer this question, however, is to compare soil tests before and after the application of fertilizer and growth of the crop to determine whether the additions did bring the soil test levels up to the critical level as predicted by the PDSS software.

The Pioneer and CP studies can also provide some information on this question. Fortunately, there were measures of soil test P taken after harvest, which makes it possible to check to see if the application of the recommended amounts of fertilizer did, indeed, result in soil test levels at or above the critical levels (Table 7). The results according to the Mehlich 1 test were that for the most part the extractable P was increased to the M or H levels by the addition of the recommended amounts of fertilizer. In a couple of cases, Lb1 and Lb2, according to the Mehlich extractant, too much P was added, however, according to the Olsen results the right amounts were added resulting in levels of M in both cases. In some cases it appears that the recommended amounts were too low, i.e. the extractable P did not increase to sufficiency level: Ln1, Ln2, and Tk2.

Table 7. Soil test data of the pioneer company's plot, a comparison before planting with after planting.

No	series	Before cropping			After cropping			Before cropping		After cropping	
		Spectro (Mehlich)		Test Kit		Spectro		Spectro (Olsen)		Spectro (Olsen)	
		mg/kg P	level		P added*, kg/ha	(Mehlich)	level	mg/kg P	level	mg/kg P	level
1	Lb	4.50	M	H*	13	17.5	VH	8	L	16	M
2	Lb	0.25	VL	VL	20.2	12.0	VH	6	L	14	M
3	Lb	3.50	M	M	14.6	7.0	H	4	L	6	L
4	Ln	6.75	M	H*	9.1	2.0	L	11	M	6	L
5	Ln	1.00	L	L	17.9	2.0	L	5	L	8	L
6	Tk	3.25	L	L	16.3	3.5	M	17	M	15	M
7	Tk	0.56	L	VL	22.1	0.6	VL	6	L	4	L
8	Pc	6.00	M	M	10.4	10.0	VH	6	L	6	L
9	Ct	2.00	L	L	17.6	5.0	M	4	L	4	L
10	Lb	19.60	VH	H	0	13.3	VH	22	H	34	H

* Estimated from a 10cm wide x 10cm depth in 75cm rows.

Next we can test for differences in yields where different approaches were used to estimate the P requirements. Those results, shown in Table 8 and Figures 7, 8 indicate that there was generally a significantly greater yield where the decision-aids were used to estimate fertilizer requirement. A limitation of this sort of analysis is that if the soils already have sufficient P there will be no yield advantage to the use of the decision-aids to estimate P requirement. A more accurate evaluation would be to assess whether the application of P where recommended, was profitable. This means asking the question was there a yield increase where the P was recommended or not. In other words, did the soil tests correctly diagnose nutrient responsive conditions and was the correct amounts of fertilizer recommended in order to meet crop needs?

Table 8. Maize yields associated with the various methods of estimating fertilizer requirement, Pioneer and CP company experiments, 2000 season.

Method	Yields, kg rai^{-1} (n=15)	Significance
Farmer’s method	918	a
Mitscherlich-Bray	1054	b
Mehlich 1	1038	b
Bray II	1090	b

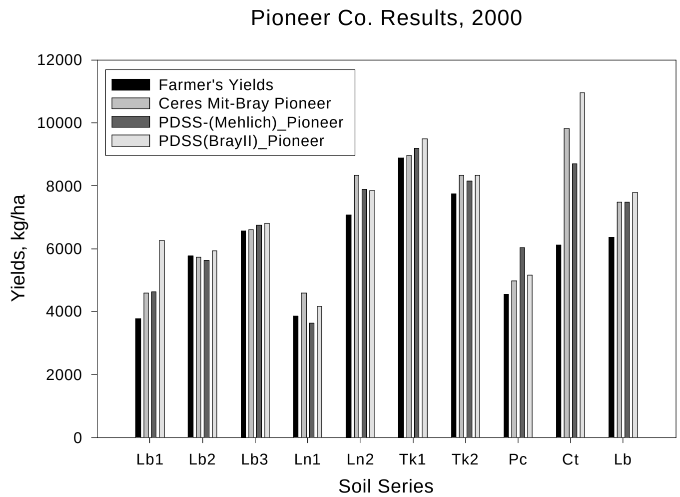

Figure 7. Corn yields, 2000 on-farm experiments testing P recommendations of PDSS.

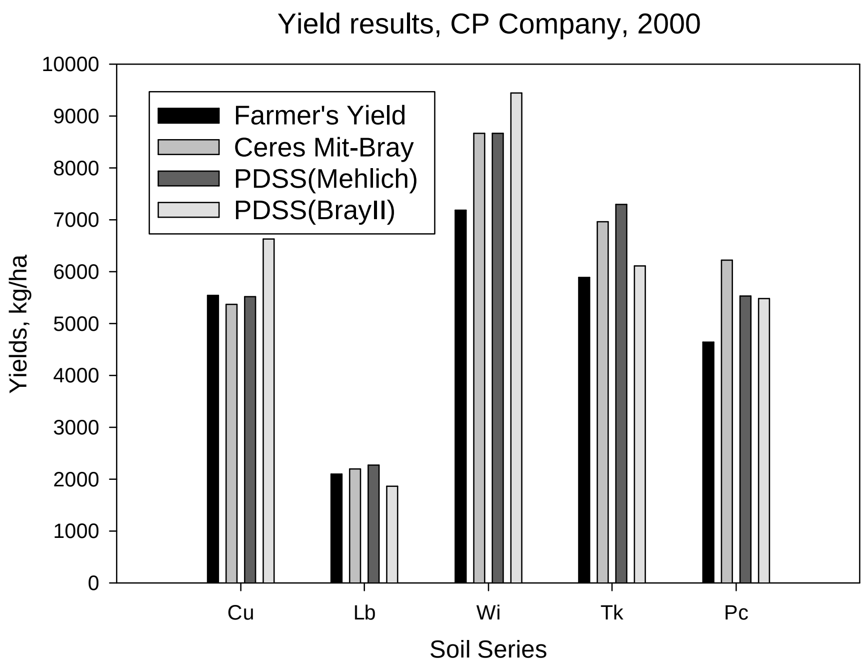

Figure 8. On-farm (2000 season) tests of PDSS diagnosis and recommendations.

Economics component - As indicated above, the economics component is the third component of nutrient management that is implemented in PDSS. There are two ways that use of soil tests and decision-aids built on them can benefit the grower economically: 1) they can save the grower from spending money for fertilizer that is not needed, and 2) they can indicate when fertilizer responsive conditions are likely. In the studies on Pioneer and CP there were cases where a simple soil test could have saved the grower money. In the case of Pioneer, there were two clear cases where the soil test indicated no need to apply fertilizer. This saved the grower an average of about 3.7 kg P2O5/rai or 94 Bt / rai. In the case of CP there were four of the five farms that tested medium or high in soil P and in this case by testing the grower would have been able to save his investment of about 100 Bt/ rai. As indicated in Table 9, there was surprisingly similar average amounts of P applied using the farmer's methods as in the PDSS recommendations, but it was not applied where responses occurred. Actual yields were somewhat higher using the decision-aids methods, but the most significant difference was that following the decision-aids, the P was applied where responses in terms of increased maize yields occurred (Table 9). Although the data are sparse there were several cases where there was a clear trend of a significant response to the addition of P fertilizer. These were in soils Ln1, where there was an approximate 13.7 kg/rai increase in yield for each kg of P2O5 added, the other series were respectively: Ln2 at 14.4, Tk2 at 5.6, Ct at 42 until about 8 kg P2O5, Cu (CP) at 11.6, and Tk (CP) at 11.8 kg/rai yield / kg P2O5. The purpose of a good decision-aid is to detect such cases so that the farmer can take advantage of such opportunities to increase yield and increase profitability.

Table 9. Economic analysis results of various methods of recommending fertilizer P.

Method	Average P2O5 recommended	Average Yield	Average Benefit* - Cost
	kg rai^{-1}	kg rai^{-1}	Baht rai^{-1}
Farmer's Practice	4.2	918	-5.32
Ceres (Mitscherlich - Bray)	9.4	1054	7.59
PDSS-Mehlich1	3.8	1038	45.2
PDSS-Bray2	4.6	1091	64.7

*Benefit: Maize yield calculated at 4Baht kg^{-1}, Cost: P calculated as DAP at 21.7Baht kg^{-1} P_2O_5. Yield response was estimated from the four levels of added P with yield maxima estimated from the approximate response curves for each soil. Baht is about 43/$US. 6.25 rai = hectare.

<u>Conclusions</u> - In summary, the phase two experiments illustrate several important evaluations of current nutrient management and suggest some areas for improvement.

- In terms of diagnosing nutrient responsive conditions, the rapid, low cost, field test kits gave results that essentially matched those obtained when the soils were packaged, mailed to a central laboratory, analyzed, and the results mailed back to the grower. This may open an alternative for on-site diagnosis of nutrient responsive conditions and savings in time and money. In terms of diagnostic accuracy, the soil tests' accuracy could be improved. Because there were differences in the amounts of N and K applied, it wasn't certain that the responses were due to P alone.
- Based on comparisons of before and after soil P analyses, the P additions, generally speaking, addressed the deficiencies identified by the soil tests. After-harvest soil P levels

were much improved over the before harvest values, and were close to expected values based on PDSS predictions.

- The economic analysis indicated the true value of the improved management information provided by the decision-aids. While the amounts of purchased and applied P were very similar between the farmer's methods and those using PDSS, it was clear that using the information provided by PDSS the fertilizers were applied where there would be response. Thus while yields were not greatly improved with the decision-aids, the profitability was increased from an average loss of about 5 baht to a profit of 40 or so. This illustrates the need to include economic analyses in the evaluation of fertilization strategy as implemented in the PDSS system.

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- Thailand Research Fund, $25,000.
- Access to data provided by network collaborators fills important information gaps in the NuMaSS database, as illustrated in this report. Although it is difficult to put a $ value on these data, it is a safe to assume that the rubustness of the NuMaSS database and its performance would suffer significantly in the absence of the information provided.

Travel and Meetings Attended

- Fred Cox - travel to Costa Rica to work with collaborators on laboratory and field trials related to P management for peach palm; travel to Ecuador to review and discuss soil P management data with Dr. Espinosa (PPI-Potaphos). September 17-18.
- Travel to Thailand to review, analyze, and interpret results from the 2000 maize experiments of the Thailand Research Fund project.

<u>Relevant Publications, Reports and Presentations at Meetings</u>

Ares, A., N.P. Falcao, R.S. Yost, K. Yuyama, E. Molina and C.R. Clement. Soil and foliar nutrient analysis as diagnostic and predictive tools in perennial tree crops. Agron. Abstr. p. 353.

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